

DINOFLAGELLATE CYST BIOSTRATIGRAPHY, PALYNOFACIES AND
PALEOENVIRONMENTAL ANALYSIS OF THE MAASTRICHTIAN AND BASAL
DANIAN, BRAZOS RIVER, TEXAS.

A Thesis

by

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ABSTRACT

This study aims to document the dinoflagellate cyst biostratigraphy and paleoenvironmental record of the Maastrichtian Neylandville and Corsicana Formations and the lower part of the Danian Kincaid Formation from the Brazos River, Texas. Rock samples are exposed to standard palynological methods for biostratigraphic interpretations. The quantitative data collected from palynological samples are combined with $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ stable isotope geochemistry and TEX_{86} and BIT Index organic geochemistry data for paleoenvironmental interpretations.

Biostratigraphically important species of dinoflagellates divide the section into three intervals. Interval 1 occurs within the Neylandville Formation, and the presence of *Alterbidinium acutulum*, *Xenascus ceratioides* and *Isabelidinium cooksoniae* indicate that this interval is not younger than early Maastrichtian. Interval 2 represents the Corsicana Formation. The presence of the late Maastrichtian species *Disphaerogena carposphaeropsis*, *Palynodinium grillator* and *Deflandrea galeata* at the base of the Corsicana Formation indicate that this interval is of late Maastrichtian age. Interval 3 occurs within the Kincaid Formation. The presence of *Carpetalla cornuta* and *Damassadinium californicum* at the base of the Kincaid Formation indicates that this interval is of Danian age. Previously published Gulf of Mexico palynology studies, as well as planktonic foraminifera and nannoplankton data confirm the age assignments of the studied interval.

Dinoflagellate species assemblages increase in diversity upwards from Interval 1 to Interval 2, and then show a small decrease above the K-Pg boundary within Interval 3, indicating that the K-Pg event was not catastrophic for the dinoflagellates. The *Cerodinium* spp. and *Spiniferites* spp. complex comprise a large proportion of the species within the section. High abundance peaks of *Glaphyrocysta* spp., *Cribroperidinium* spp., and *Yolkinigymnium lanceolatum* occur within Interval 2.

Two intervals in the section are dominated by peridinioid dinoflagellates, measured by the Peridinioid/Gonyaulacoid (P/G) ratio. The first one occurs within Interval 2 and contains peaks of the P/G ratio that correlate with increases in $\delta^{13}\text{C}$, suggestive of an increase in paleoproductivity. Two more peaks occur within Interval 3. Bottom water $\delta^{18}\text{O}$ temperatures determined from benthic foraminifera and sea surface temperatures determined from TEX₈₆ organic geochemistry show an overall cooling trend from Early Maastrichtian to the K-Pg boundary.

DEDICATION

To my mother, Sengul Aydin, and my father, Irfan Aydin

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1. INTRODUCTION

This study focuses on the paleontological and paleoenvironmental record through the Maastrichtian to early Danian sediments on the coastal plain of the northwestern Gulf of Mexico. In particular, the dinoflagellate cyst assemblages of the lower to upper Maastrichtian and lower Danian are documented, including their response to the Cretaceous-Paleogene (K-Pg) impact event. Since the K-Pg boundary strata in Texas and the biotic record just before and after the impact event have been investigated by many scientists. Based on recently discovered exposures along the Brazos River in Falls County, central Texas, this study provides a longer stratigraphic record, the biota and the paleoenvironmental conditions of the Maastrichtian and Danian in Texas.

The study area is located on the northwestern side of the Texas Gulf Coastal Plain (Figure 1). Several outcrop sections from the study area have been previously described and studied, with an emphasis on the Brazos River K-Pg boundary (e.g. Pessagno, 1969; Smith and Pessagno, 1973; Jiang and Gartner, 1986; Hansen et al., 1987; Yancey, 1996; Smit et al., 1996; Keller et al., 2007; Keller et al., 2011; Hart et al., 2012; Yancey and Liu, 2013). The study sections are located between 31°07'30" to 34°47'00" N and 96°47'08" to 96°47'07" E (Reagan Quadrangle, 7.5 minutes series topographic maps) in between Eloise and Cedar Springs. The samples were collected from both the Brazos riverbed and from exposed bluffs (Figure 1).

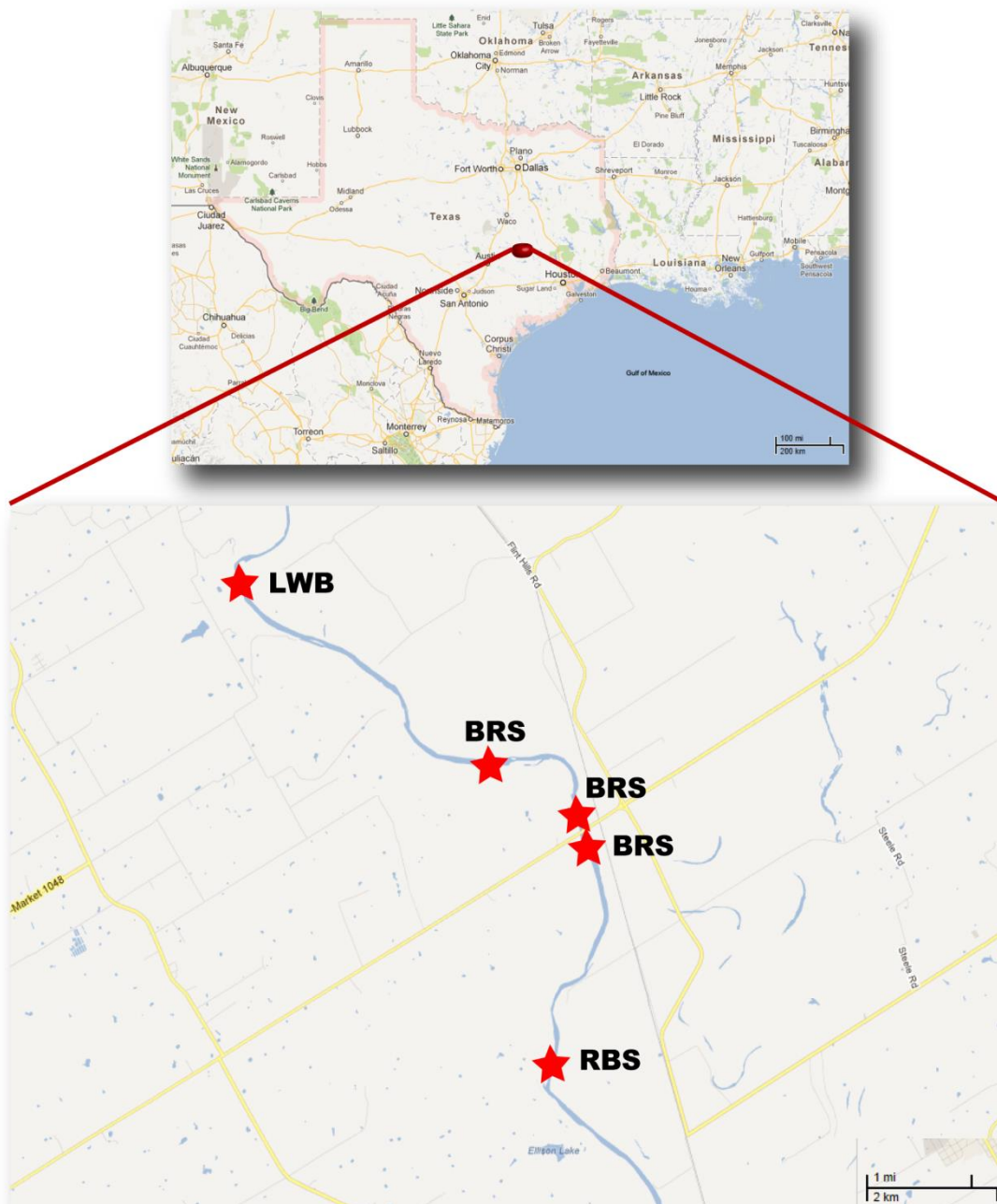


Figure 1. Study area map. LWB: Lake Winiwaca Bluff; BRS: Brazos River Section; RBS: Riverbank South (Hart et al., 2012).

Dinoflagellates are a major component of the primary plankton of the oceans. Their cysts are useful tools for biostratigraphy and paleoenvironmental studies. The oldest well-established fossil dinoflagellate cysts are of Triassic age. Their species diversity reached peaks in the Albian and Maastrichtian (MacRae et al., 1996; Powell, 1992). Throughout their geological history, dinoflagellate cysts show fewer declines in their diversity (MacRae et al., 1996) compared to other microfossil groups (e.g., planktonic foraminifer, calcareous nannoplankton, diatoms and radiolaria).

Differences in dinoflagellate assemblages occur along transects from inshore to offshore environments, associated with changes in salinity, primary productivity and eutrophication (De Vernal and Marret, 2007; Marret, 2003). Changes in relative abundances of dinoflagellate cysts can be used as a parameter to determine transgressive-regressive cycles and changes in eustatic sea-level (Habib and Miller, 1989). Relative sea-level drop through the Maastrichtian was interpreted from variations in relative abundances of certain species (Firth, 1987, 1993).

Highest and lowest occurrences of biostratigraphically important taxa provide relative time determinations in stratigraphic sections, and differences in abundance of taxa provide evidence of changing environmental conditions. Species abundances vary with geographical regions, providing interpretation of local paleoenvironments. Dinoflagellate cyst evolution makes them useful for biostratigraphic age dating (Table 1).

Table 1. Biostratigraphic zonations from previous studies of the Gulf and Atlantic Coastal Plains.

| STAGE | ZONATION | | | | | | | |
|---------------|----------------------------------|----------------------------------|-----------------------|----------------------------------|------------------------------------|---|--------------------|--|
| | PLANKTONIC FORAMINIFERA | DINOFLLAGELLATES | | | | | | |
| | Texas (Smith and Pessagno, 1973) | Texas (Zaitzeff and Cross, 1970) | Georgia (Firth, 1987) | Maryland (Benson, 1976) | New Jersey (Koch and Olsson, 1977) | New Jersey (Aurisano, 1989) | | |
| Danian | P0 | Unnamed | Interval C | Unnamed | Unnamed | | Unnamed | |
| Maastrichtian | <i>A. mayorensis</i> | Zone B and C | Interval B | Monmouth Assemblage zone C | <i>P. basilium</i> | <i>D. cretacea</i> | <i>D. galeata</i> | |
| | <i>G. gansseri</i> | | Interval A | Monmouth Assemblage zone A and B | | <i>D. magnifica</i> <i>S. australina</i> | <i>C. ?robusta</i> | |
| | <i>R. subcircumnodifer</i> | Zone A | | | <i>P. infusorioides</i> | <i>P. infusorioides</i> | <i>D. wilsonii</i> | |

Zaitzeff and Cross (1970) studied the dinoflagellate taxonomy and stratigraphy of the Maastrichtian Corsicana and Neylandville Formations near Austin and the Escondido and Olmos Formations of Frio County, Texas. Benson (1976) also reported dinoflagellate biostratigraphy and taxonomy of the Monmouth and Brightseat Formations from Round Bay, Maryland. May (1980) studied dinoflagellate cyst assemblages from Campanian-Maastrichtian strata of Atlantic Highland, Monmouth County, New Jersey. Another Upper Cretaceous dinoflagellate biostratigraphy study of New Jersey was published by Aurisano (1989). Firth (1987) reported Maastrichtian and Danian dinoflagellate cyst biostratigraphy of a U.S. Geological Survey core from

Albany, Georgia. Firth (1993) studied dinoflagellate assemblages and their relation to the sea level fluctuations in Georgia. Prauss (2009) reported marine palynology of the K-Pg boundary at Brazos River, Texas. He compared dinoflagellate assemblages to isotope chemistry for one outcrop section (Cottonmouth Creek) and two cores (KT-1, Mullinax-1).

2. REGIONAL GEOLOGY

The study area is located on the northwestern margin of the Gulf of Mexico (Figure 2), a small, deep ocean basin on the southern edge of North America connected to the Atlantic Ocean basin to the east. The Gulf is bounded by continental crust on all sides, except for a connection to the Atlantic Ocean through a narrow opening between the Florida Peninsula and the Yucatan Peninsula. It is bounded on the north by the United States, on the east by the Florida Peninsula, on the west by Mexico and on the south by the Yucatan Peninsula. The northern margin of the Gulf of Mexico has a wide continental shelf, built from sedimentary deposits derived from the erosion of the interior of North America. During the Cretaceous, waters of the Gulf of Mexico connected with the Western Interior Seaway, a long-lasting epicontinental sea that extended from the Gulf of Mexico to the Arctic Ocean (Kauffman, 1984; Sohl, 1987).

The breakup of Pangea occurred during the Mesozoic with rifting that separated Laurasia from Gondwana and opened the mid-Atlantic Ocean basin. An east-west directed segment of the rift zone, located from Florida to Texas, opened up and led to formation of the Gulf of Mexico. As the rift widened, sea-floor spreading developed within the rift zone, as the Yucatan Peninsula block moved southward from the rest of North America. From the Late Jurassic to Early Cretaceous, rotational spreading occurred along this east-west trend as ocean crust formed in the newly created Gulf of Mexico (Pindell and Kennan, 2001; Marton and Buffler, 1999).

By the end of the Early Cretaceous, carbonate reefs developed on the continental margin of the Gulf of Mexico, producing the typical morphology of the basin (Winker and Buffler, 1988).

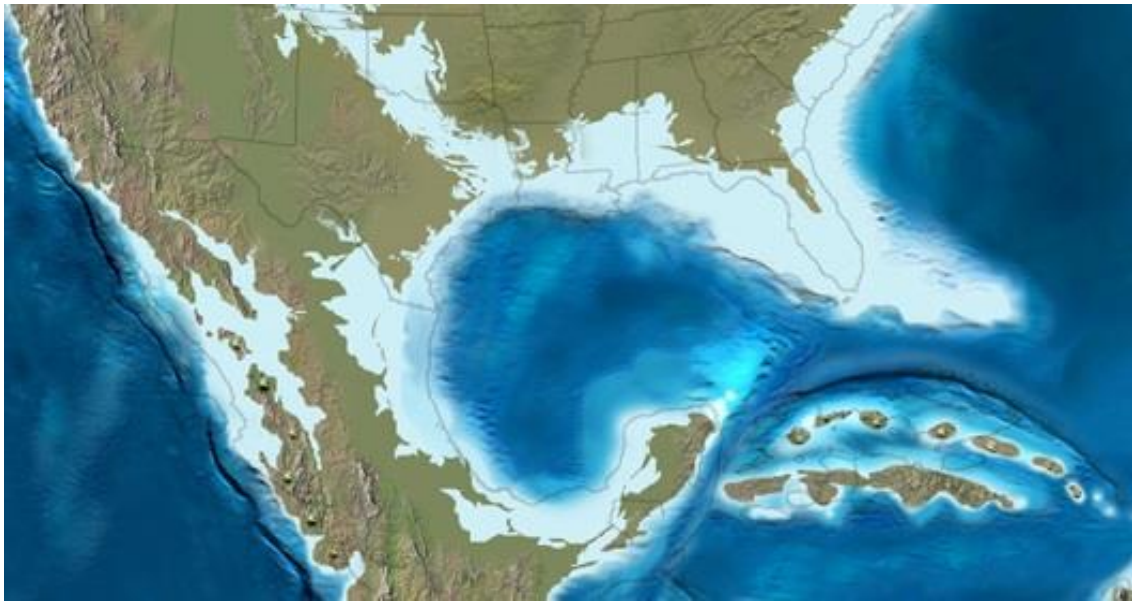


Figure 2. The Gulf of Mexico and the Western Interior Seaway shoreline during the Late Cretaceous (Blakey, 2011).

The Cretaceous was a time of high global sea level because of high spreading rates and increasing volume of mid-ocean ridges. The highest level occurred during the Turonian. There was a gradual fall of the global sea-level from the Turonian to the Maastrichtian (Haq et al., 1987). The global sea level fall after the Turonian warm period may have been associated with the development of continental ice sheets on Antarctica (Bornemann et al., 2008; Stoll and Schrag, 2000).

The Western Interior Seaway was getting shallower and closing during the Late Cretaceous (Haq et al., 1987; Mancini and Puckett, 2005) (Figure 2). Tectono-eustatic cycles and numerous important fourth-order transgressive-regressive cycles modified the shape, bathymetry and sedimentary composition of the basin from latest Albian to middle Maastrichtian (Kauffman, 1969, 1977). During the Cretaceous there were short-term cyclic changes in sea-level superimposed on the long-term trend of global sea-level fall. These small cyclic variations in sea-level are recognized as sequence units within the Cretaceous deposits, but their cause is unknown. During the Cretaceous there were also times of wide spread ocean anoxia that are recognized as oceanic anoxic events (OAE).

The Navarro group is characterized by siliciclastic-dominated progradation, marine transgression and periods of shelf starvation with lags of phosphorite (Mancini and Puckett, 2005). Features such as bored phosphatized mud clasts, steinkerns, and shark, fish and mosasaur teeth and bone fragments, are indicators of nearshore to inner-shelf formed disconformities (Galloway, 2008) (Figure 2). The Maastrichtian Corsicana Formation was deposited during a highstand and the Kincaid Formation accumulated as a last unit of offshore sediment deposition. The origin and structural history of the Western Interior Epicontinental Sea was controlled by plate tectonic activity, regional tectonics in the western Cordilleran orogenic belt and the structural attachment of the frontal part of the Cordilleran thrust belt.

Increased rates of sediment deposition during the Late Cretaceous progradation of the shelf margin produced aggradational depositional environments in this portion of

the Gulf Coast (Davidoff and Yancey, 1993). Thus, the environmental conditions for the Brazos river site from the Latest Cretaceous to early Paleocene was mid-to outer shelf (Figure 3) (Schulte et al., 2006).

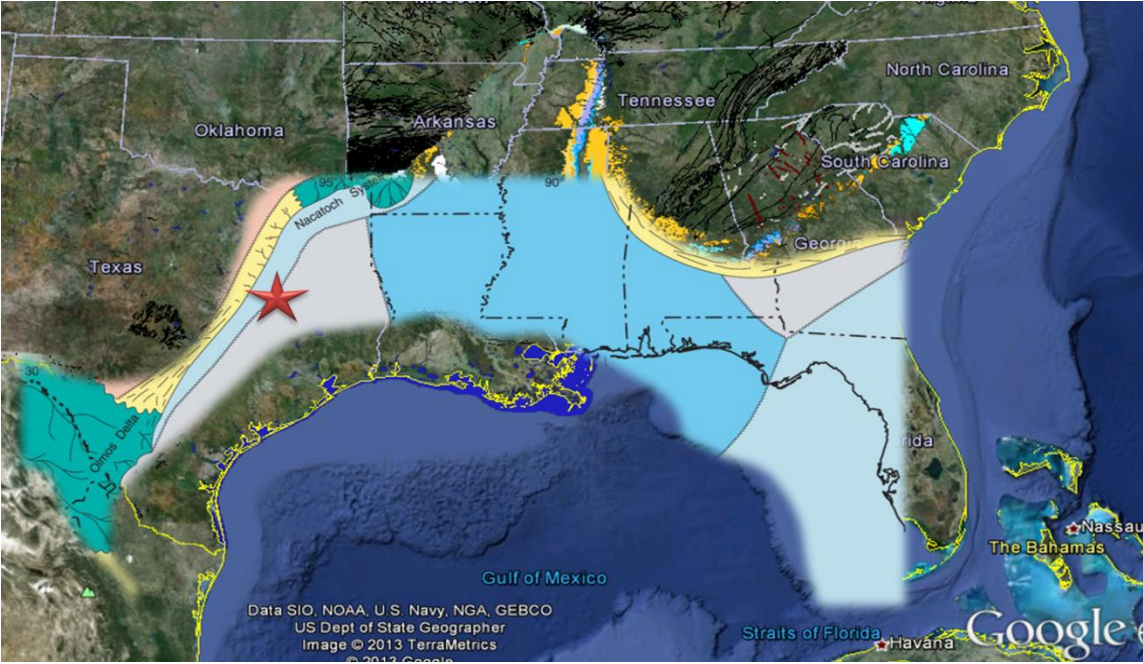


Figure 3. Shoreline position for the northern Gulf of Mexico during the Early Paleocene (Overlying map is modified after Galloway, 2008).

3. LITHOSTRATIGRAPHY

From early Maastrichtian to the early Danian, sediments are mostly fine grained mudstone, as characterized by the Neylandville Formation, the Corsicana Formation, and the Kincaid Formation (Figure 4). The carbonate content of these mudstones varies, reflecting changes in the production and deposition of calcareous plankton and benthic organisms, and local cementation. During the middle Maastrichtian, fine-grained sediment deposition was interrupted by deposition of a wedge of sand onto the continental shelf in east Texas and Arkansas, represented by the Nacatoch Sand Formation (Figure 4). The top of the Maastrichtian is overlain by a thin layer of coarser sediment that was spread across the shelf by the high energy disturbance produced by the Chicxulub impact event. The Wills Point Formation overlies the Kincaid Formation and it is a transitional unit of silt-rich sediment that marks the beginning of a change to coarser sediment deposition of the Paleocene-Eocene Wilcox group (Stephenson, 1941; Yancey, 1996; Schulte et al, 2006).

| AGE | FORMATION |
|----------------------|------------------|
| DANIAN | Wills Point Fm. |
| | Kincaid Fm. |
| MAASTRICHTIAN | Corsicana Fm. |
| | Nacatoch Sand |
| | Neylandville Fm. |

Figure 4. Generalized stratigraphic section of the study area (Stephenson, 1941).

3.1. Neylandville Formation

The Neylandville Formation is a gray calcareous mudstone unit with minor amounts of sand (Sellards et al., 1932; Stephenson, 1941). Stephenson (1941) placed the formation in the *Exogyra cancellata* macrofossil zone. The Neylandville Formation was sampled in an outcrop 7 km upriver from Highbank 413 Bridge at Lake Winiwaca Bluff (Figure 5). This outcrop was sampled on August 2012 and November 2012 during low water conditions. Lithology of this unit consists of clay-rich, fossiliferous mudstone with abundant macrofossils and inoceramid shell fragments. Sediments in the lower part of the bluff exposures contain many small fresh biotite crystals, suggesting a volcanic ash component to the sediment (Figure 6, 8).



Figure 5. Location map of the Lake Winiwaca Bluff section.

The Neylandville Formation lies stratigraphically below the Nacatoch Formation (McGowen and Lopez, 1983), a sheet sand unit present between the Neylandville Formation and the Corsicana Formation. This sand unit is not exposed along the river and was not sampled.

3.2. Corsicana Formation

The Corsicana Formation lies on top of the Nacatoch Formation and beneath the Littig Member of the Kincaid Formation in the study area (Yancey, 1996). Smith and Pessagno (1973) described the lithology of the Corsicana Formation as dark to light gray to grayish tan calcareous mudstone, locally glauconitic and occasionally with quartzose

silty fine sand, containing varying amounts of mica and phosphatic fish remains, as well as small pyrite nodules. Corsicana strata exposed along the Brazos River near the Rt. 413 bridge have the same lithology described by Smith and Pessagno (1973), although lacking glauconite (Figure 7). The Brazos River exposures also contain a 0.5 m thick sand layer about 9 m below the top of the formation, as well as a thin volcanic ash bed (Figure 8).

Hill (1901) proposed separate names “Corsicana beds” and “Kemp beds” as sub-members of the top of the Navarro Formation in north-central Texas, and also recognized the Nacatoch Formation sandstone in the middle of the Navarro. The strata below the Nacatoch were separated and placed in the Neylandville Formation. Adkins (in Sellards et al, 1932) redefined the Corsicana to include all the variable strata above the Nacatoch Formation and below the top of the Navarro. In the Brazos River Valley there is no lithologic basis for subdividing strata between the Nacatoch Formation and the Cretaceous-Paleogene (K-Pg) boundary into lower and upper units, so these strata belong to a single formation. The Corsicana Formation is better defined as a formation and that name is applied to the section exposed along the Brazos River.



Figure 6. The Neylandville Formation at Lake Winiwaca Bluff.

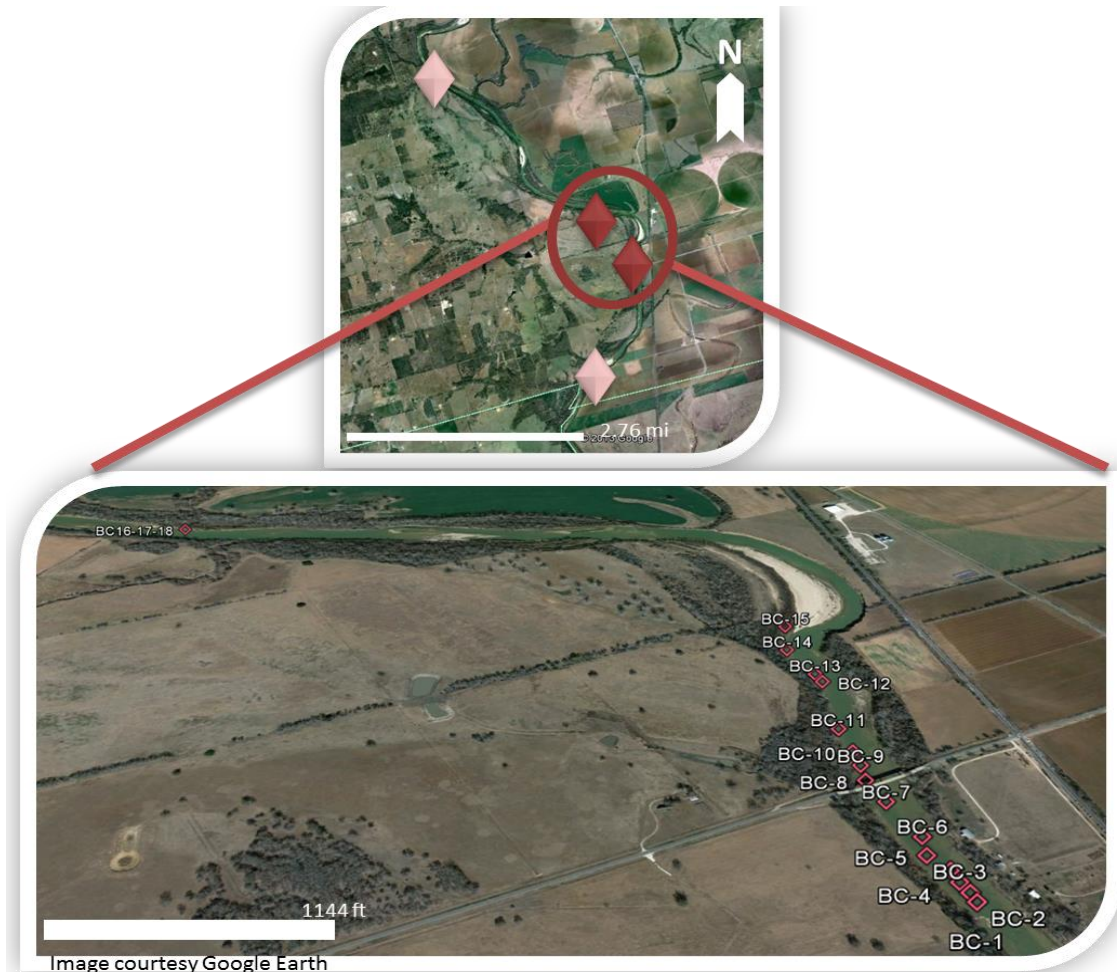


Figure 7. Location map of Brazos River section.

Smith and Pessagno (1973) reported an approximate thickness of 75- 90 meters for the formation. The Corsicana Formation lies on top of the Nacatoch Formation and disconformably beneath the Littig Member of the Kincaid Formation (Yancey, 1996). Smith and Pessagno (1973) described the lithology of the Corsicana Formation as dark gray to light gray or grayish tan calcareous mudstone, locally glauconitic and occasionally quartzose silty and fine sandy with varying admixtures of muscovite mica,

phosphatic fish tooth and bone fragments, and small pyrite and marcasite nodules.

Hence, based on previous studies, the Corsicana Formation is herein considered as late Maastrichtian section of the Cretaceous sediments from the Brazos River.

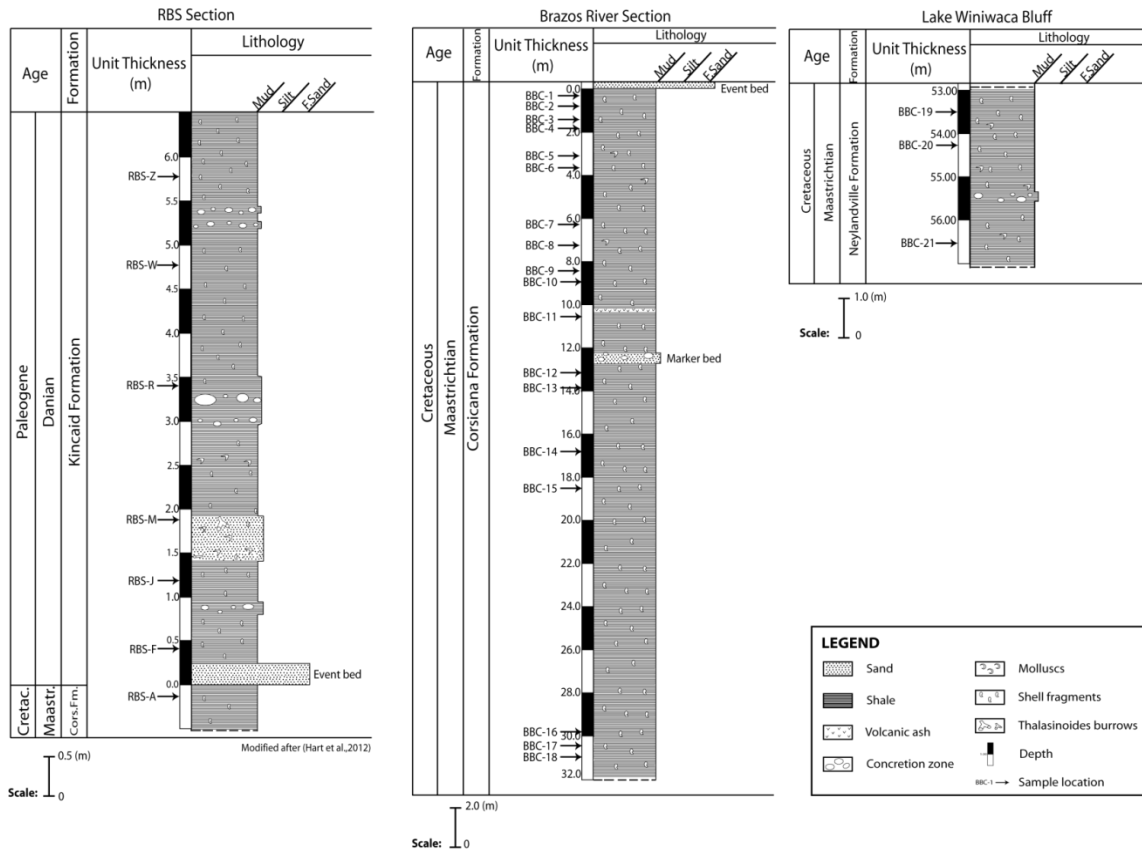


Figure 8. Stratigraphic units of the studied section. The marker bed is identified in the Mullinax-1 core (Abramovich et al., 2011).

3.3. Kincaid Formation

The Kincaid Formation has a fine-grained lithology similar to the mudstones of the underlying Corsicana Formation and foraminiferal sand deposits in the lower part of

the formation. It is separated from the Corsicana by a meter thick layer of sandstone and mass flow mudstone that were deposited as a result of Chicxulub impact disturbance on the continental shelf. The formation contains a lower Littig Member and an upper Pisgah Member, with the Littig Member containing five meters of fossiliferous condensed section deposited during maximum flood conditions and sea level highstand (Hansen et al., 1987; Hart et al., 2012; Yancey, 1996). The Littig Member is extensively exposed along the Brazos River and along the Cottonmouth Creek and Darting Minnow Creek tributaries to the river (Figure 9). Calcareous concretion units occur above the steinkern bearing condensed deposit and a pyrite concretion horizon is present at the top of the Littig Member (Yancey, 1996). Rock samples of RBS Section, an outcrop located on the bank of the Brazos River between Cottonmouth Creek and Darting Minnow Creek (Hart et al., 2012), were used in this study (Figure 8).

4. GEOLOGICAL AGE

The first detailed study of microfossil biostratigraphy of latest Cretaceous sediments of Texas was by Pessagno (1969), who presented a planktonic foraminiferal zonation of the Late Cretaceous extending from the Cenomanian to Maastrichtian. This work was followed by documentation of the planktonic foraminiferal biostratigraphy of the Corsicana Formation at several localities in Texas by Smith and Pessagno (1973). Two Maastrichtian assemblage zones were distinguished and a *Globotruncana gansseri* zone was identified in the Corsicana Formation (Figure 10). The *Globotruncana gansseri* zone was divided into a lower *Globotruncana aegyptica* subzone, distinguished by the presence of middle Maastrichtian planktonic foraminifera found in sediments of the Corsicana Formation exposed in Travis Creek, and a late Maastrichtian *Racemiguembelina fructicosa* zone present in the Corsicana Formation throughout north-central Texas. A latest Maastrichtian *Abathomphalus mayaroensis* zone was reported to be absent, presumably removed by erosion. Abramovich et al. (2011) published on Maastrichtian planktonic foraminifera in the Brazos River Section and used the CF zonation of Li and Keller (1998).

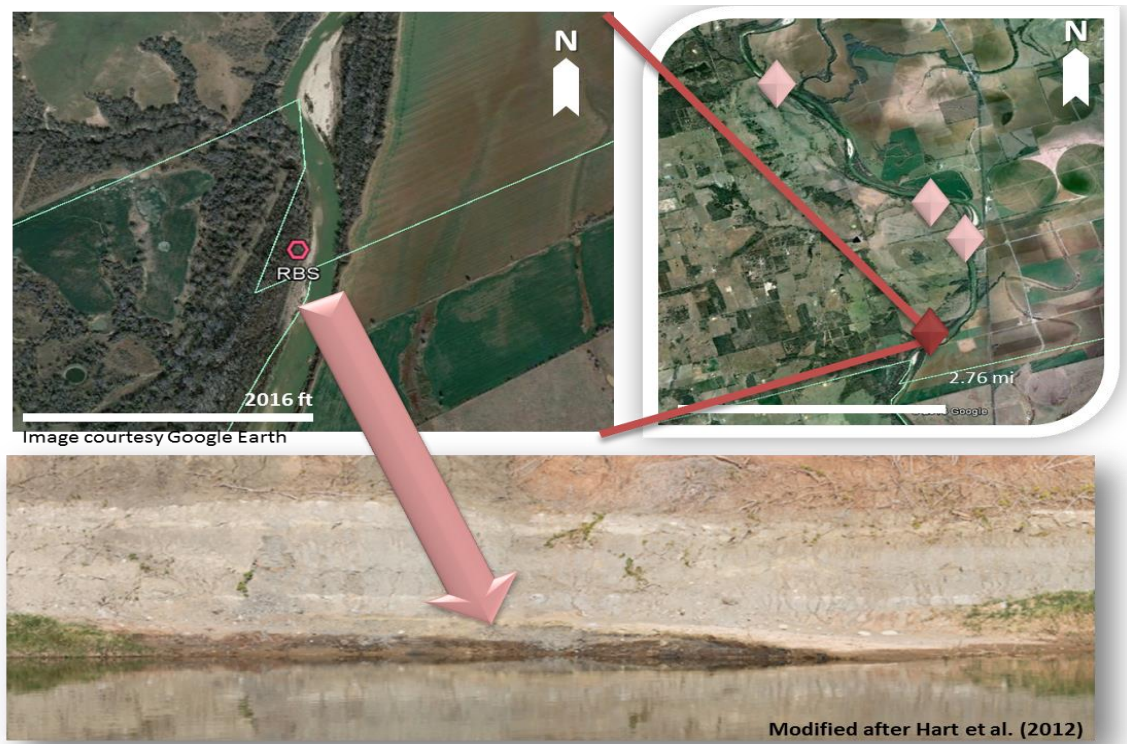


Figure 9. Location map of the Riverbank South (RBS) section.

A detailed study of Maastrichtian calcareous nannoplankton biostratigraphy was reported by Jiang and Gartner (1986). They reported three biostratigraphic zones from two different localities in east-central Texas: the late Maastrichtian *Micula murus* zone and the early Tertiary *Markalius astroporus* and *Cruciplacolithus tenuis* zones (Figure 10). They reported that the K-Pg boundary interval in east-central Texas contains a continuous record of deposition from the late Maastrichtian to the Danian. This conflicted with the conclusions of Pessagno (1969) and Smith and Pessagno (1973), who interpreted an erosional unconformity at the top of the Cretaceous based on the absence of indicator species of the planktonic foraminiferal zone *Abathomphalus mayaroensis*.

This study was followed by another calcareous nannoplankton biostratigraphy of the K-Pg boundary in Brazos River by Tantawy (2011), who reported results similar to Jiang and Gartner (1986).

The first dinoflagellate biostratigraphy of Maastrichtian sediments from east-central Texas was reported by Zaitzeff and Cross (1970). The Corsicana Formation and Kemp Clay were reported as different sedimentary units within the late Maastrichtian. The Neylandville and Nacatoch Formations also were considered one unit. Three biostratigraphic zones of dinoflagellates were reported in their study: Zone A (oldest), Zone B and Zone C (youngest) (Table 1).

Danian biostratigraphy in Texas remained undeveloped after the early studies of Plummer (1931) until Jiang and Gartner (1986) reported on the basal Danian nannoplankton zones in the Brazos River section. At the same time, the recognition of a mass extinction event at the end of the Cretaceous led to documentation of two new basal Danian planktonic foraminiferal zones, zones P0 (partial range zone of *P. cretacea*) and Pa (taxon range zone of *P. eugubina*) (Berggren and Pearson, 2005).

The Brazos River Section contains the most complete record of the K-Pg boundary in Texas. Keller (1989) reported on planktonic foraminiferal biostratigraphy of three exposures of the section from the Brazos River. She defined the K-Pg boundary based on the lowest occurrences of Danian marker species (Keller et al., 2011). This is in conflict with the current definition for the placement of the K-Pg boundary (Molina et al., 2006). Accordingly, she places the base of the Danian at a horizon 0.5 meters above the Molina et al. (2006) definition of the K-Pg boundary. Some reports on

biostratigraphy of the K-Pg boundary follow the Keller definition (e.g. Prauss, 2009; Abramovich et al., 2011 and Tantawy, 2011).

| AGE | FORMATION | Planktonic foraminifera biostratigraphy (Smith and Pessagno, 1973) | Calcareous nannofossil biostratigraphy (Jiang and Gartner, 1986) |
|---------------|---------------------|--|--|
| DANIAN | Kincaid Formation | Unsampled interval | C. tenuis zone |
| | | | M. astroporus zone |
| MAASTRICHTIAN | Corsicana Formation | Globotruncana contusa-stratiformis Assemblage zone | Micula murus zone |
| | | Globotruncana fornicata-stratiformis Assemblage zone | |
| | Nacatoch Sand | Unsampled interval | Unsampled interval |
| | Neylandville Marl | | |

Figure 10. Previously reported biostratigraphic zonation of Upper Cretaceous of Texas.

Prauss (2009) reported dinoflagellate cyst biostratigraphy of K-Pg boundary sediments from the Brazos River. He placed the K-Pg boundary at the base of the P0 foraminiferal zone. Prauss reported the highest occurrences (HO) of *Dinogymnium* spp. and *Yolkinigymnium* spp., and the lowest occurrences (LO) of *Membranilarnacia tenella* and *Damassidinium californicum* to bracket a Keller-defined placement of the K-Pg

boundary. He reported the first occurrence of *Carpatella cornuta* to be within planktonic foraminiferal zone P1b.

Other useful zonations of the Campanian and Maastrichtian section of the Gulf of Mexico region are a Campanian ostracode zonation of central Texas by Chimene and Maddocks (1984) and an oyster macrofossil zonation by Stephenson (1941) based on the ranges of *Exogyra ponderosa*, *Exogyra cancellata*, and *Exogyra costata*. The oyster zonation provides a general determination of the stratigraphic position for the Campanian and Maastrichtian of Texas. A report on ammonites present in the late Maastrichtian of the Brazos River section was presented by Kennedy et al. (2001).

5. METHODS

5.1. Sampling Procedure

Twenty eight samples were collected from above and below the Cretaceous-Paleogene boundary on the Brazos River. Six samples were collected from the Paleogene and twenty two samples were collected from the Maastrichtian section. Six Paleocene samples and one Maastrichtian sample were provided by Dr. Malcolm Hart (Plymouth University) from the Riverbank South (RBS) section. Twenty one samples, approximately one kilogram per sample, were collected from the Brazos River bed and from bluffs during shallow water conditions. Clean collecting tools were used for each sample to prevent contamination and each sample was immediately placed in a labeled sample bag and sealed.

Samples were placed in the oven for 24 hours to dry; then they were placed in new plastic sample bags.

5.2. Standard Palynological Acid Maceration Techniques

Samples were treated in a freezing and thawing process to disaggregate the clay component before applying standard palynological acid maceration techniques (Vidal, 1988). For freezing and thawing process:

- 1- Approximately 40-gram samples were taken from a sample bag.
- 2- The outer surface of the sample was removed to prevent contamination.

3- The sample was crushed to granulated powder and placed in 50 ml centrifuge tubes.

4- Each centrifuge tube was filled with 50% sodium sulfate solution and placed in a freezer for 12 hours.

5- The frozen sample was taken to room temperature and left for approximately 12 hours until thawed. These steps were repeated 5-6 times until all clay material was broken down.

6- The sample was sieved in 120 μm , 63 μm and 20 μm sieves and a 2 ml subsample were collected from the sieve in each step.

All remaining sieved material was collected in a 400 ml beaker for standard palynological acid maceration techniques, outlined below.

1- The sieved material was washed in a 400 ml beaker.

2- Cold concentrated HCl was added to the beaker to remove carbonates, and ethanol was used to break the surface tension of bubbles, also tracer spore *Lycopodium* tablets were added. When the reaction was completed, the sample was washed and centrifuged until neutralized.

3- Cold concentrated HF was added to the sample and left for 24 hours to remove silicate and clay minerals. The sample was washed and centrifuged until neutrality, and then the material was sieved at 20 μm to remove any remaining clay particles.

4- 2 ml subsamples collected from each sample for palynofacies analysis.

5- 5% sodium hypochlorite (Clorox) solution was added to the sample for 5 minutes to oxidize organic material, and then the sample was washed and centrifuged.

6- 5-6 drops of ammonium hydroxide were added and the solution was left for 5 minutes to dissolve oxidized products before washing and centrifugation.

7- The residue was placed in 15 ml centrifuge tubes and centrifuge tubes were filled with $ZnCl_2$ solution (specific gravity > 2.0) to separate organic material from mineral debris.

8- Samples were centrifuged for 30 minutes starting from low to high speed. The organic residue was collected from the top in a clean pipette, and placed in a new centrifuge tube; then it was diluted with water. The organic residue was again sieved at 20 μm .

9- The sample was washed with glacial acetic acid, then acetolyzed in 9/1 solution of acetic anhydride and sulfuric acid for 15 minutes in a heating vessel.

10- The sample was washed again with glacial acetic acid, then centrifuged.

11- The sample was treated with a mixture of 50% glacial acetic acid and 50% water and centrifuged again.

12- The palynological residue was placed in 1.5 ml centrifuge tubes and 3-4 drops of ethanol were added.

13- A few drops of residue were put on a cover glass and allowed to dry on a hot plate. A few drops of Norland Optical Adhesive was placed on microscope slide, and then dry cover glass was placed on top, and slides were left the under ultraviolet light for a few minutes until the adhesive hardened.

Samples were processed at the Pollen Laboratory in the Department of Anthropology at Texas A&M University. Specimen locations on slides were given as right (R) and above (U) in millimeters to the lower left corner of the cover slide.

Specimen photos were taken on a Zeiss Microscope, using a Spot Camera connected to a Macintosh computer. Photos were captured on Spot software and saved as jpg files. An Olympus FV1000 Confocal Microscope was also used for imaging species, especially those that were hard to determine on regular light microscope.

5.2.1 Counts of Palynomorphs and Calculation of Absolute Abundances

Dinoflagellate cysts and terrestrial palynomorphs (pollen and spores) were counted only if they comprise at least half of the specimen. Three hundred specimens were counted per sample. *Lycopodium* spores were added to samples to calculate absolute abundances of palynomorphs in samples. Absolute abundances of palynomorphs were calculated according to the following formula by Benninghoff (1962):

$$C = \frac{d_c \times L_T \times t}{L_C \times w}$$

where

C: concentration of palynomorphs per gram dry sediment

d_c : number of counted palynomorphs

L_T : number of *Lycopodium* spores per tablet

t: number of tablets added to sample

L_C : number of counted *Lycopodium* spores

w: weight of dry sediment sample

5.3 Geochemistry Analyses

5.3.1 Sample Preparation For $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ Stable Isotope Analyses

Approximately 20 g rock samples were used to collect specimens of *Lenticulina* spp. for $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ analyses. Seven to ten *Lenticulina* specimens from each sample were placed in small vials. Next, each specimen was cleaned and weighted. Three specimens for each sample (approximately 50 μg) were used for each isotope analysis. Samples were run for oxygen and carbon stable isotope analyses using an isotope ratio mass spectrometer and Kiel IV carbonate device in the Department of Geological Sciences at the University of Texas at Austin.

Modern species of *Lenticulina* are reported as being in disequilibrium with ambient water (Grossman, 1984). $\delta^{18}\text{O}$ data for *Lenticulina* spp. was corrected to $\Delta^{18}\text{O}_{\text{eq}} = -0.47 \text{ ‰}$ (Grossman, 1984).

Estimated temperatures based on $\delta^{18}\text{O}$ is calculated according to the following formula by Epstein and Mayeda (1953);

$$T^{\circ}\text{C} = 16.5 - 4.3(\delta^{18}\text{O}_{\text{CaCO}_3} - \delta^{18}\text{O}_{\text{w-AMW}}) + 0.14(\delta^{18}\text{O}_{\text{CaCO}_3} - \delta^{18}\text{O}_{\text{w-AMW}})^2$$

Where;

$\delta^{18}\text{O}_{\text{CaCO}_3}$: $\delta^{18}\text{O}$ of calcium carbonate relative to VPDB

$\delta^{18}\text{O}_{\text{w-AMW}}$: $\delta^{18}\text{O}$ of ambient water versus “average marine water”.

5.3.2 TEX₈₆ and BIT Index Organic Geochemistry Analysis

About 12 g from each of the 21 Maastrichtian samples were processed for Glycerol Dialkyl Glycerol Tetraethers (GDGT) content. Samples were run in a high performance liquid chromatography-atmospheric-pressure positive-ion chemical-ionization mass spectrometer (HPLC-APCI-MS) in the Department of Earth Sciences, University of Utrecht.

6. RESULTS AND DISCUSSION

6.1 Biostratigraphy

Twenty-eight samples of the Neylandville, Corsicana and Kincaid Formations from the Brazos River, Texas yielded well preserved, highly diverse assemblages of dinoflagellate cysts, acritarchs, pollen and spores. Dinoflagellate cysts dominate most palynomorph assemblages, while a few samples are dominated by terrestrial palynomorphs and woody debris. Dinoflagellate cysts are identified to genus and species level when possible. Other palynomorphs are identified to general groups, such as pollen/spores, bisaccate pollen, and foraminiferal linings, except for the stratigraphically important species of the pollen *Wodehousia spinata*, *Aquilapollenites* and the acritarch *Fromea fragilis*. A total of 98 dinoflagellate cysts and acritarchs and two pollen are identified (Table 2).

The lowest species abundance of dinoflagellate cysts occurs in samples of the Neylandville Formation with 46 species, and the highest species abundance occurs in the Corsicana Formation with 67 species. The lower Danian Kincaid Formation contains 48 species. The stratigraphic occurrences of dinoflagellate cyst taxa are reported in the following section based on their stratigraphic depth (- meters) or height (+ meters) below and above the K-Pg boundary event bed (= 0 m).

6.1.1 Dinoflagellate Cyst Zonation of the Brazos River Section

6.1.1.1 Interval 1

Interval 1 occurs in the Neylandville Formation from -53.5 m to -56.6 m and contains highest occurrence (HO) datums of *Alterbidinium acutulum*, *Xenascus ceratoides* and *Isabelidinium cooksoniae* at -53.5 m, and lowest occurrence (LO) datums of *Phelodinium africanum*, *Pierceites pentagonus*, *Dinogymnium sibiricum*, *Senegalinium laevigatum* and *Deflandrea galeata*. at -53.5 m. Thirteen species of dinoflagellate cysts are restricted to this interval: *Chatangiella micrachanta*, *Alterbidinium acutulum*, *Spinidinium ornatum*, *Xenascus ceratoides*, *Isabelidinium cooksoniae*, *Chatangiella ditissima*, *Dinogymnium digitus*, *Senegalinium sp. 1*, *Cerbia tabulata*, *Batiacasphaera reticulata*, *Chatangiella granulifera*, *Manumiella cretacea* and *Dinoflagellate sp.1* (Table 2).

6.1.1.2 Interval 2

Interval 2 corresponds to the Corsicana Formation from -31 m to the K-Pg boundary (0 m). Sixty seven species occur within Interval 2, with 33 of those species continuing higher in the section into Interval 3. Nine species have HO datums close to the top of Interval 2 at the highest level sampled within the Corsicana Formation: *Achomosphaera ramulifera*, *Dinogymnium nelsonense*, *Glaphyrocysta cf. G. reticulosa*, *Hystrichosphaeridium tubiferum*, *Palynodinium sp. 1*, *Glaphyrocysta expansa*, *Tanyosphaeridium variecalamum*, *Conosphaeridium striataconum* and *Circulodinium distinctum*. The highest HO datums in the Brazos River Section occur at 0.2 m below the

K-Pg boundary. Fifteen species have their HOs at various levels within the Corsicana Formation (Table 2).

Four species have acmes within this interval: *Yolkinigymnium lanceolatum*, *Glaphyrocysta perforata*, *Glaphyrocysta cf. G. reticulata*, and *Cribroperidinium wetzelii*. *Glaphyrocysta cf. G. reticulata* and *Cribroperidinium wetzelii* have abundance peaks in the middle of Interval 2 at -18 m, whereas *Yolkinigymnium lanceolatum* and *Glaphyrocysta perforata* acmes occur immediately below the top of Interval 2 at -0.1 m in the RBS section.

6.1.1.3 Interval 3

Interval 3 encompasses the Kincaid Formation from the K-Pg boundary to + 5.7 m in the RBS Section. Forty eight species occur within Interval 3 and three species have their LOs at the base of this interval: *Manumiella druggii*, *Carpetalla cornuta* and *Alterbidinium cf. A. circumum*.

The biostratigraphically important late Maastrichtian species of *Dinogymnium acuminatum* and *Disphaerogena carposphaeropsis* have HOs at + 0.6 m to + 2.0 m above the base of Interval 3. Species of *Dinogymnium* spp. are usually considered to be restricted to the Cretaceous and their HOs have been used to mark the K-Pg boundary (Brinkhuis and Leereveld, 1988). *Disphaerogena carposphaeropsis* and *Dinogymnium* spp. appear to be reworked into the base of Interval 3 in the RBS section. They occur rarely in the Kincaid Formation and have poor preservation, indicated by damage to the cyst wall.

6.1.2 Biostratigraphic Comparison with Previous Studies

Zaitzeff and Cross (1970) studied the dinoflagellate biostratigraphy of the Navarro Group (Maastrichtian) in south Texas (Frio County) and the Austin area (Travis County), Texas. They described three biostratigraphic zones from oldest to youngest as zone A, B and C. Zone A occurs in the “Neylandville-Nacatoch” formations and contains the HOs of *Deflandrea? micrachanta* (*Chatangiella micrachanta*), *Hystriosphæridium* sp. 2 (*Conosphæridium striatoconum*), *Dinogymnium digitus* and *Deflandrea acuminata* (*Alterbidinium acutulum*). They reported that this zone is characterized by the abundance of *Dinogymnium digitus* and *Dinogymnium nelsonense* (Figure 11).

In the Brazos River Section, Interval 1 is similar to zone A of Zaitzeff and Cross (1970). *Chatangiella micrachanta*, *Alterbidinium acutulum* and *Dinogymnium digitus* have their HOs at the top of Interval 1 (Figure 11). However, Interval 1 is characterized by the common occurrences of *Hafniasphaera septata* and *Apteodinium cf. A. granulatum* and does not have common *Dinogymnium* species (Table 2).

Moshkovitz and Habib (1993) reported late Maastrichtian to Danian calcareous nannofossil and dinoflagellate cyst assemblages in core and outcrop from the Braggs, Alabama section. A succession of LO datums of late Maastrichtian indicator species occurs in the Prairie Bluff Formation below the K-Pg boundary, including *Trithyrodinium evittii* (lowest), *Palynodinium grillator*, *Thalassipora pelagica* and

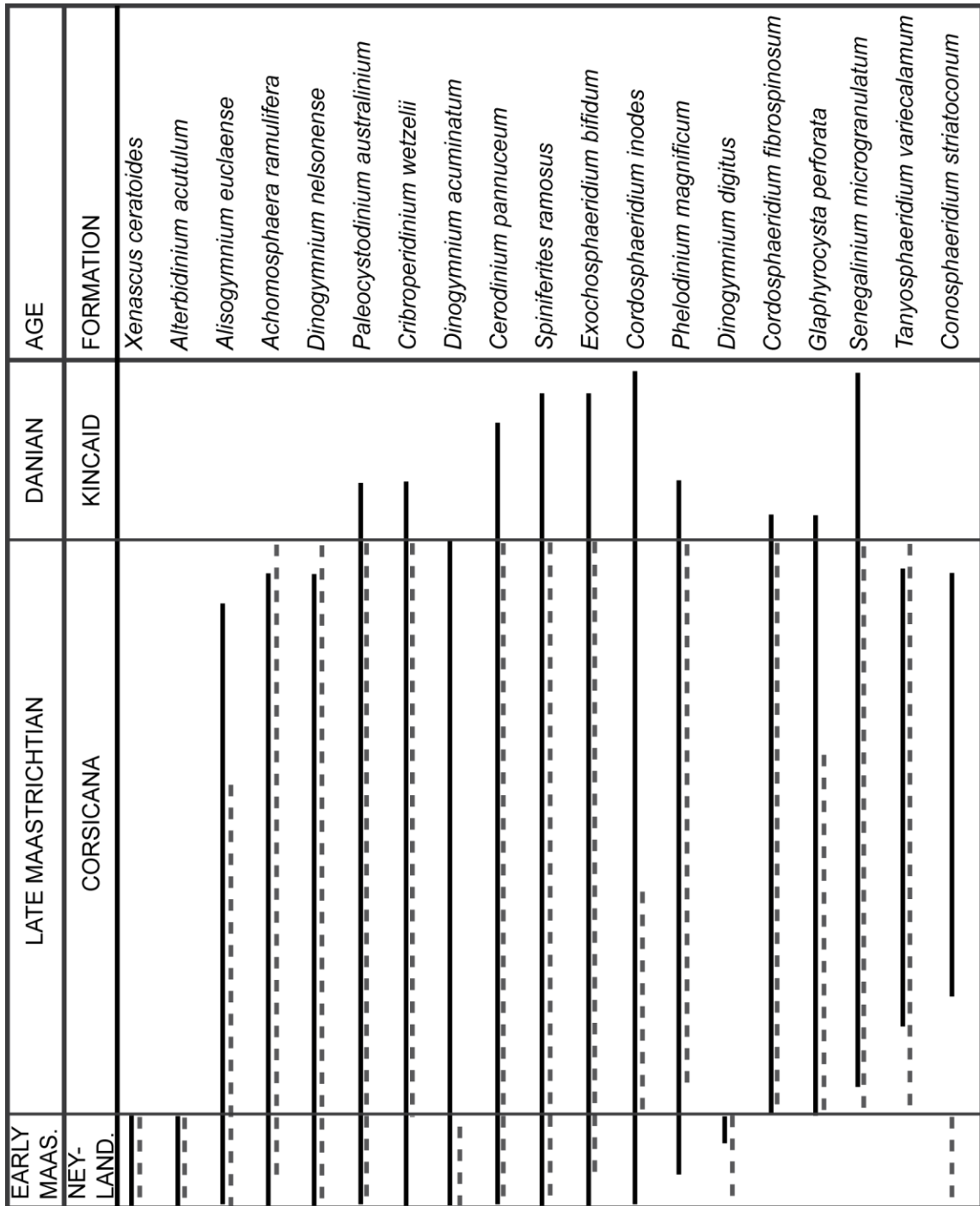


Figure 11. Biostratigraphic comparison of Zaitzeff and Cross (1970) and the Brazos River Section. Solid lines represent occurrence of species in the Brazos River Section, dashed lines represent occurrence of species from Austin (Travis County) by Zaitzeff and Cross (1970).

Disphaerogena carposphaeropsis (highest). In the Braggs section these species have HOs in about the same horizon 1.5 m below the K-Pg boundary (Figure 12).

In the Brazos River section, *Palynodinium grillator* and *Trithyrodinium evittii* have LOs at -30.9 and -53.5 m. *Palynodinium grillator* has its HO at -16.9 m, while *Trithyrodinium evittii* ranges up through the Danian part of the section, similar to its occurrence in the Braggs core (Moshkovitz and Habib, 1993) (Figure 12).

Disphaerogena carposphaeropsis has its LO at -30 m and HO at +0.6 m in the Brazos River section, similar to its range in the Braggs, Alabama section. The HO and LO of *Deflandrea galeata* in the Brazos Valley section is restricted to Maastrichtian strata. Within the Braggs section *D. galeata* is reported within Danian sediments. However, this is interpreted as reworking by Moshkovitz and Habib (1993) (Figure 12).

Firth (1987) reported on the Maastrichtian and Early Danian dinoflagellate biostratigraphy of the USGS Albany Core in Georgia. He described three dinoflagellate assemblages in the core, intervals A (oldest), B and C (youngest). Interval A was interpreted as early Maastrichtian in age and is characterized by the common to abundant occurrences of *Chatangiella robusta* and *Exochosphaeridium robustum*, and sparse to common occurrences of *Cerodinium boloniense*. The HO of *Spongodinium delitiense* is close to the top of Interval A. Interval B is interpreted to be of late Maastrichtian age and is characterized by very high diversity of dinoflagellate cysts. The HO of *Isabelidinium cooksoniae* is about 7 m below the K-Pg boundary, while the HO of *Alterbidinium acutulum* is about 10 m below the boundary. *Disphaerogena carposphaeropsis*, *Manumiella seelandica* and *Palynodinium grillator* are reported in one sample just

below the K-Pg boundary (Figure 12). *Thalassipora pelagica* has its LO close to the base of this interval, while its HO is just above the K-Pg boundary. Also, abundance peaks of *Manumiella seelandica* and *Trithyrodinium evittii* occur just below the K-Pg boundary.

In the Brazos River section, *Disphaerogena carpospharopsis*, *Trithyrodinium evittii*, *Thalassipora pelagica* and *Palynodinium grallator* have their LOs 30 m below the K-Pg boundary, much lower than their LOs reported in Firth (1987). Also, no abundance peaks of *Manumiella seelandica* or *Trithyrodinium evittii* occur in the Brazos River section.

In the Davis-Hopkins core in Georgia (Moshkovitz and Habib, 1993), the Late Maastrichtian to Danian species *Thalassipora pelagica* has a lowest appearance horizon at 750.6 m. *Disphaerogena carposphaeropsis* has a lowest appearance horizon at 722.6 m. The HO of *Palynodinium grallator* is in the Cretaceous sample at 713.4 m and extends down to the base of the core (806.4 m). *Seniosphaera inornata* occurs in the lowest Paleocene sample at 678.7 m and ranges up to 661.3 m. *Damassidinium californicum*, has its LO at 661.9 m, 6.8 m above the LO of *Seniosphaera inornata* (Figure 12).

Similar to the Davis-Hopkins core, the LO of *Thalassipora pelagica* is at -30.9 m in the Brazos River Section; *Disphaerogena carpospharopsis* is at -30 m, below the K-Pg boundary. The LO of *Damassidinium californicum* is at 1.3 m above the K-Pg boundary in the Brazos River Section. *Seniosphaera inornata* is not recorded from the Brazos River Section.

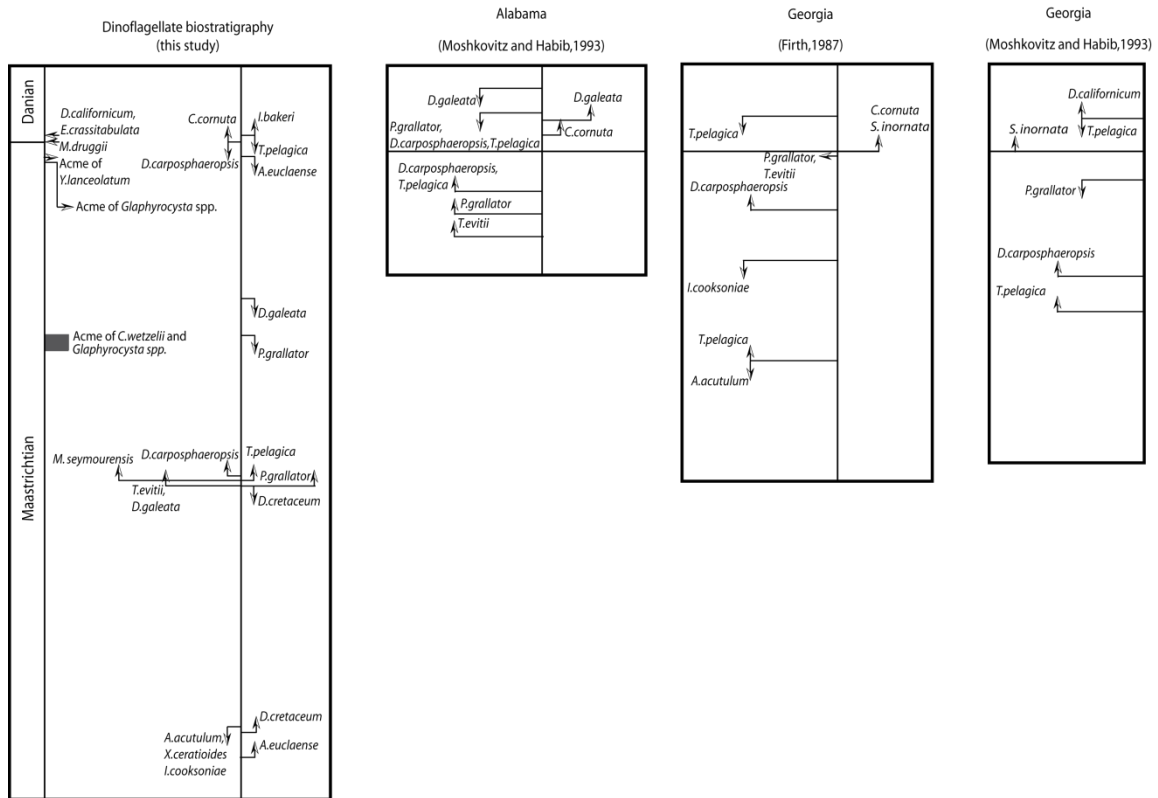


Figure 12. Biostratigraphic correlation of the studied section to previous Gulf of Mexico studies.

6.2 Assemblage Characteristics

The palynological assemblages consist of dinoflagellates, terrestrial spores and pollen. Palynofacies are determined by the proportion of amorphous organic matter facies compared to vascular tissue facies remains in the manner described by Habib and Miller (1989), which can be used to interpret marine influence versus terrestrial influence. The amorphous organic facies (AOF) is considered as fecal remains of zooplankton feeding on phytoplankton and other organic materials. The vascular tissue

facies (VTF) is considered as abundant well preserved vascular tissue remains and other organic material coming from land plants (Habib and Miller, 1989). The ratio of dinoflagellate cysts to spores-pollen (marine/terrestrial) (M/T) is used to interpret proximity to shoreline or to sediment source (Habib and Miller, 1989). The section is divided into six sub-intervals based on the palynofacies (amorphous versus vascular tissue) and the dinoflagellate/spore-pollen (M/T) ratio.

Interval 1 contains a low M/T ratio and a vascular tissue facies (Figure 13). This suggests the presence of a shallow marine depositional environment or a greater riverine influence within deposits of the Neylandville Formation.

Interval 2 contains two amorphous organic matter facies separated by a vascular tissue facies. The highest M/T ratio corresponds with the amorphous organic facies and also corresponds to the highest dinoflagellate cyst species abundance at the base of Interval 2. The middle of Interval 2 contains a vascular tissue facies, a low M/T ratio, and low dinoflagellate cyst species abundance. The top of Interval 2, below the K-Pg boundary, contains increased relative abundance of dinoflagellates and an amorphous organic facies, and higher dinoflagellate cyst species abundance (Figure 13).

Interval 3 has a moderate and variable M/T ratio. The palynofacies changes upward from a more terrestrial vascular tissue facies to a more marine amorphous organic facies (Figure 13). The lowest part of Interval 3 contains abundant VTF content and low M/T ratio, while the middle part varies in VTF content. The highest part of Interval 3 contains an AOM facies that corresponds to the deepest water deposits of the section.

Several species of dinoflagellate cysts have abundance acmes in the Brazos River section: *Glaphyrocysta* spp., *Cribroperidinium* spp., *Spiniferites-Achomosphaera-Hafniasphaera* (S-A) species complex, *Cordosphaeridium-Exochosphaeridium* (C-E) group and *Senegalinium-Cerodinium* (S-C) group. The acmes of *Glaphyrocysta* spp., *Cribroperidinium* spp., *Spiniferites-Achomosphaera* complex, *Cordosphaeridium-Exochosphaeridium* group, and the *Senegalinium-Cerodinium* group correspond with the highest M/T ratio in Interval 2. Two acmes of *Yolkinigymnium lanceolatum* occur within Interval 2, and correlated with lower peaks of M/T values and low dinoflagellate cyst species abundance.

6.2.1 Comparisons of Dinoflagellate Assemblages with Previous Studies

Comparison of the dinoflagellate abundance peaks and diversity trends of Zaitzeff and Cross (1970)'s Austin section and the Brazos River section shows close similarity. *Exochosphaeridium* spp. (=Forma A sp.1 in Zaitzeff and Cross, 1970) has an abundance peak in both the Austin and the Brazos River sections. *Glaphyrocysta* spp. (=Forma B sp.1 in Zaitzeff and Cross, 1970) has two abundance peaks within the Corsicana Formation that is present in both sections. *Spiniferites* spp. (= *Hystrichosphaera ramosa* var.1 in Zaitzeff and Cross, 1970) has two distinct abundance peaks at the base and the top of the Corsicana Formation in both sections (Figure 14).

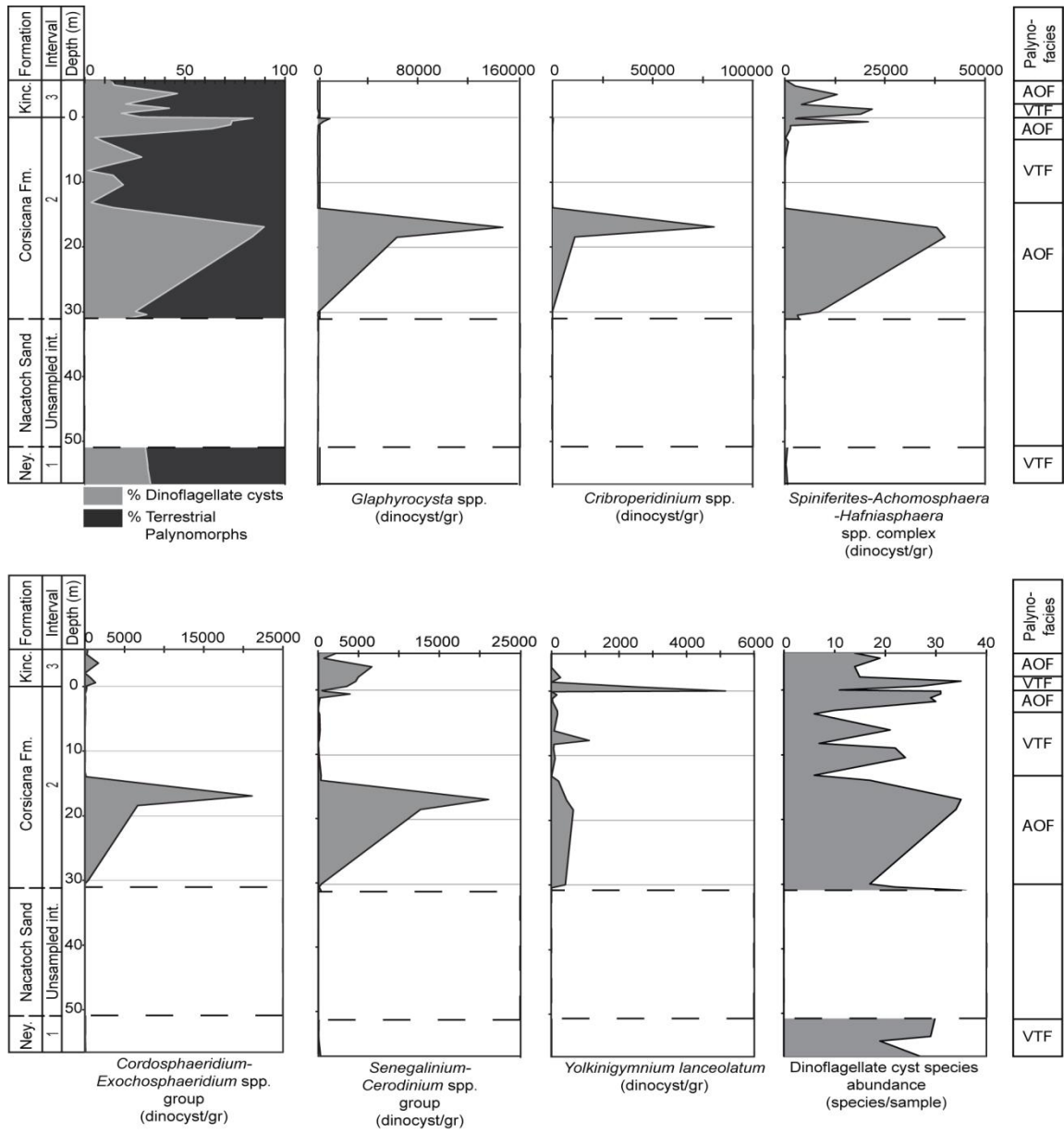


Figure 13. Dinoflagellate versus pollen-spore (M/T) ratio, and absolute abundances (dinocyst/gr) of dinoflagellate cysts in the Brazos River Section.

Firth (1987, 1993) studied dinoflagellate cyst assemblages in the USGS Albany Core and Ft. Gaines Core from Georgia. In the USGS Albany Core, all of the samples

contain the amorphous organic facies of Habib and Miller (1989). *Spiniferites ramosus* increases in abundance from the lower Maastrichtian to upper Maastrichtian, corresponding with increasing abundance of terrestrial palynomorphs. Upper Maastrichtian assemblages of the Albany Core are dominated by the *Spiniferites-Achomosphaera* species complex. In contrast, the dinoflagellate assemblages from the Ft. Gaines core contain high relative abundances of *Areoligera* spp., *Cribroperidinium wetzellii*, *Glaphyrocysta reticulosa*, the *Paleocystodinium-Andalusiella* (P-A) complex, the *Spiniferites-Achomosphaera* (S-A) species complex, and the *Senegalinium obscurum-Cerodinium pannuceum* (S-C) species complex. The S-C complex in the Ft. Gaines core corresponds with more marine influence, similar to its occurrence in the Brazos River Section. The S-A complex has its greatest abundance in association with high occurrences of terrestrial palynomorphs in the Ft. Gaines core. The highest occurrences of the S-A complex and *G. reticulosa* are associated with less marine influence in the upper Maastrichtian within the Ft. Gaines core. In contrast, within the Albany core and the Brazos River Section the occurrence of the S-A complex occurs in association with *Cribroperidinium* complex and *Glaphyrocysta* complex, correlating with a greater marine influence.

The species abundance peaks of the Brazos River section and the Eastern Gulf Coast sections are similar, but the Brazos River Section contains an expanded uppermost Maastrichtian *Micula prinsii* nannofossil zone, whereas the Eastern Gulf Coast sections contain an expanded middle Maastrichtian *Lithraphidites quadrites* nannofossil zone.

Although these are not stratigraphically equal they do show that several taxa have repeated abundance peaks throughout the middle to upper Maastrichtian.

There are conflicting interpretations of the marine versus terrestrial influences of several dinoflagellate taxa. Increasing relative abundances of *Achomosphaera* spp., *Spiniferites* spp., *Cyclonephelium* spp. and *Glaphyrocysta* spp. were interpreted as indicators of shallowing water conditions by Brinkhuis and Zachariasse (1988) and Hultberg and Malmgren (1986). Firth (1993) noted that increasing abundances of *Spiniferites ramosus* from the lower to upper Maastrichtian in the Albany Core correlate with increasing abundances of terrestrial palynomorphs. Habib and Miller (1989) noted that increasing abundances of *Achomosphaera medusettiformis* and *Glaphyrocysta reiintexta* correspond to increasing abundances of marine phytoplankton as well as amorphous organic palynofacies. Atta-Peters and Salami (2004), Downie et al. (1971), and Prauss (2009) report that increasing abundance of *Spiniferites* spp. and *Areoligera/ Glaphyrocysta* spp. correlate with open marine conditions. Thus, there is conflicting palynological evidence of changing relative abundances of *Achomosphaera* spp., *Spiniferites* spp., *Areoligera* spp. and *Glaphyrocysta* spp. in association with less open marine conditions. Despite these conflicting interpretations of marine influence or distance to shore, there are other factors in addition to terrestrial influence that control species abundances in the marine environment. Dinoflagellate cysts are extremely sensitive to small changes in nutrient availability, water temperature and salinity (Brinkhuis, 1994; Dale, 1996; Pross and Schmiedl, 2002). It seems likely that changes

in species abundance in the study area are affected by regional differences in terrestrial runoff, chemical composition within the water column, as well as temperature.

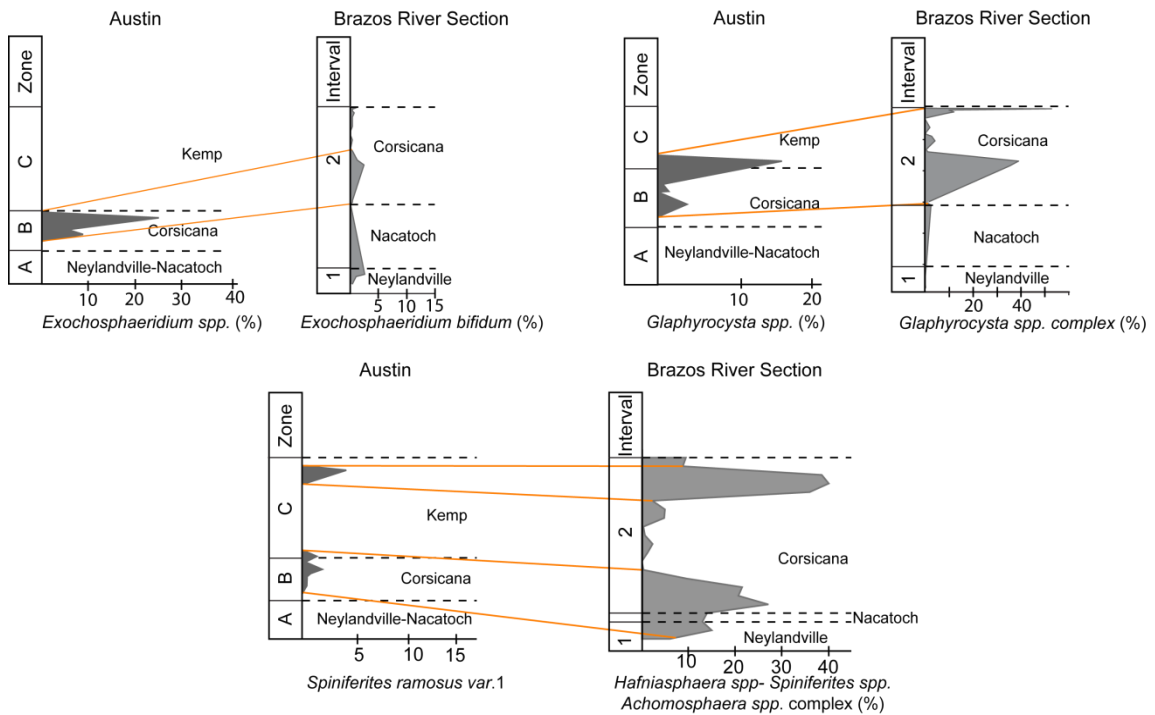


Figure 14. Comparison of species abundances in the Brazos River versus Austin (Travis County) (Zaitzeff and Cross, 1970).

6.3 Paleoenvironments

Sediments of the Corsicana Formation are composed of mudstones and were deposited in a middle to outer shelf marine environment, based upon the water depth (75-150 m) determined from benthic and planktonic foraminifera (Yancey and Liu, 2013). The lack of sandstone layers (except for one thin sandstone bed at -9 m) in the

Corsicana Formation indicates deposition below normal storm wave base. The diverse protist and invertebrate biota indicate normal salinity marine waters.

Sediments of the Kincaid Formation are composed of mudstone and sandstone deposited in a middle to outer shelf marine environment, based upon water depth from 50-200 m determined by benthic and planktonic foraminifera (Yancey and Liu, 2013). Sandstone of the Kincaid Formation within the RBS section consists of a condensed section deposited during maximum flooding conditions on the shelf (Hart et al., 2012). The sandstones in this formation occur in the planktonic foraminifera P1 zone and are composed dominantly of foraminiferal tests and phosphate steinkerns (Hansen et al., 1993; Yancey, 1996; Hart et al., 2012).

The Peridinioid/Gonyaluroid (P/G) ratio is calculated based on total number of peridinioid cysts versus gonyaluroid cysts to interpret paleoproductivity. Peridinioid dinoflagellates are mostly heterotrophic organisms, feeding on diatoms or phytoplanktons, while the gonyaluroid dinoflagellates are autotrophic organisms. Overall, gonyaluroid cysts dominate the Brazos River assemblages. There are four P/G ratio peaks within the section. Two peaks occur within the Corsicana Formation, correlating with the vascular tissue facies and low values of $\delta^{13}\text{C}$. Brinkhuis and Biffi (1993) have related low values of $\delta^{13}\text{C}$ with paleoproductivity. This would indicate an increase in primary productivity the within interval from -14 m to -6 m. Two high P/G ratios also occur within the Kincaid Formation. Although there are no isotope analyses available for these Kincaid Formation strata, the P/G ratio may indicate high paleoproductivity (Figure 15).

Paleotemperature determinations for the Brazos River section are made using TEX₈₆ and δ¹⁸O analyses. Both measures of paleotemperature indicate a cooling trend from early Maastrichtian to the K-Pg boundary in the Brazos River section. Sea surface temperatures (SST) based on TEX₈₆ indicates a 3°C decline within the late Maastrichtian. δ¹⁸O paleotemperatures based upon the benthic foraminifer *Lenticulina* spp. (assuming constant seawater δ¹⁸O of -1‰) suggests a 13°C decline from the early Maastrichtian to the K-Pg boundary (Figure 15). The warm temperatures for Interval 1 are likely an artifact of low seawater δ¹⁸O values due to freshwater influence, as indicated by the M/T ratios. In contrast, M/T ratios for Interval 2 indicate a greater marine influence. Thus, seawater δ¹⁸O was likely close to -1‰ and temperatures were likely close to the isotopic temperatures, about 18-20°C.

Although TEX₈₆ indicates a cooling trend of only 3°C, these values are for the higher part of the water column. Paleodepth determinations based on benthic foraminifera indicate water depths of 75-100 m for the Corsicana Formation, consistent with the waters being cooler than surface waters. The δ¹⁸O values within Interval 2 are internally consistent within this interval and suggest stability of bottom waters during deposition of Interval 2 of the Corsicana Formation.

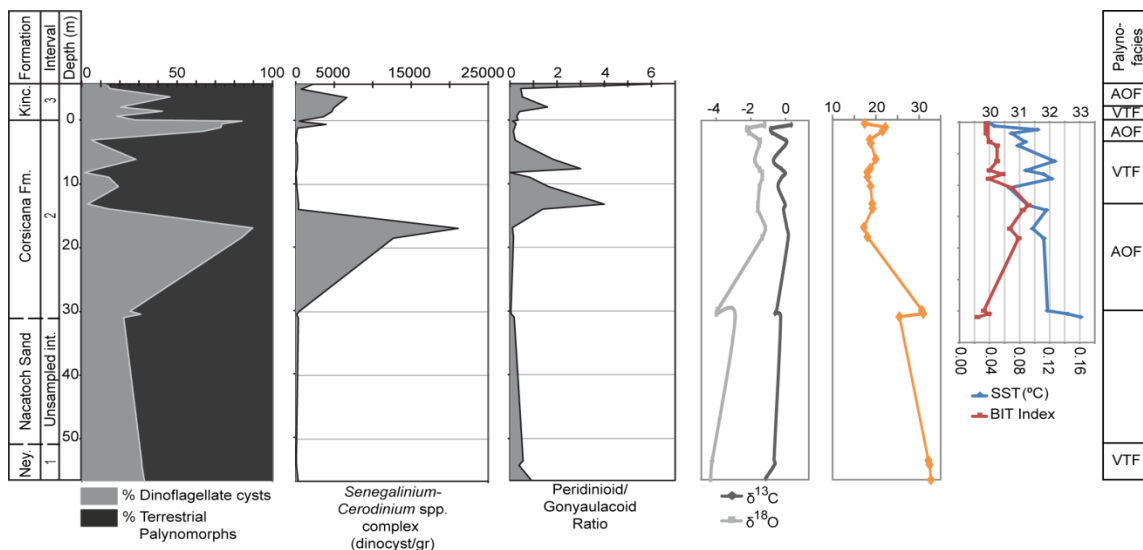


Figure 15. Correlation of dinoflagellate/spore-pollen ratio, the P/G ratio and TEX86 and BIT Index organic and $\delta^{18}\text{O}$ (corrected) and $\delta^{13}\text{C}$ stable isotope geochemistry.

A measure of the riverine water influence to marine water of the shelf is determined using the BIT Index (Branched and Isoprenoid Tetraether index). The BIT Index has low values (0.02-0.04) at the base and the top of the Corsicana Formation and slightly higher values (0.09) in the middle of the formation. BIT is an index based on relative abundances of terrestrially derived tetraether lipids versus crenarchaeol, the membrane lipid of non-thermophilic crenarchaeota and is used to describe relative amount of fluvial input to marine environments (Hopmans et al., 2004). It varies between 0.00 and 1.00, and terrestrial organic matter such as soil and riverbed sediments show high values (>0.9), while marine organic matter has low values (0.02-0.83). Thus the BIT Index decreases seaward from the shoreline (Kim et al., 2006). The BIT index has highest values within the interval containing high M/T ratios and acme peaks of

Glaphyrocysta spp., *Cribroperidinium* spp., *Spiniferites-Achomosphaera-Hafniasphaera* species complex, and *Cordosphaeridium-Exochosphaeridium*. This indicates a higher terrestrial influence within water masses interpreted more marine, within the middle of the Corsicana Formation. Hopmans et al. (2004) reported increases in BIT Index values in localities within the North Sea coincident with decreases in salinity. In the Brazos River section, acme peaks of dinoflagellate cysts occur within the interval where BIT index values are high (Figure 15). Hypothetically, this might indicate decrease in salinity in an open marine environment caused by greater riverine input. However, more future work needs to be done to improve the interpretation.

7. SYSTEMATIC PALYNOLOGY

In this section 96 dinoflagellate cyst taxa, two acritarchs, and two angiosperm pollen taxa are listed. Other terrestrial palynomorphs are only grouped as either “pollen/spores” or “gymnosperm pollen”.

Phytoplankton cyst taxa are identified down to species level when possible. Only unknown species and “cf” affinities of dinoflagellates are described or discussed, along with their measurements, stratigraphic occurrences and previously reported occurrences.

. New taxa are treated informally in this study, since a Master’s thesis is not considered as a valid publication by the International Code of Botanical Nomenclature (McNeill et al., 2012).

The suprageneric classification of dinoflagellate cysts follows the informal categories of Wall and Dale (1968) and Eaton (1980):

- 1- Dinogymnioid group: This group of dinoflagellate cysts is similar to modern genera *Gymnodinium*. They are biconical, one layered and do not show paratabulation, except for having an apical aperture. A paracingulum and parasulcus are usually evident, along with two flagellar scars in the central parasulcul region.
- 2- Gonyaulacoid group: This group has a similar tabulation with the modern genus *Gonyaulax*, comprising four apical, six precingular, six cingular, six postcingular and one antapical paraplates (4’, 6’’, 6c, 5’’’,

1p, 1''''). They have apical, precingular and combination apical-precingular archeopyles.

- 3- Peridinioid group: This group has similar tabulation with the modern genus *Peridinium*, comprising four apical, three apical intercalary, seven precingular, six cingular, five postcingular and two antapical paraplates (4', 3a, 7'', 6c, 5''', 2''''). They have different combinations of apical and intercalary archeopyles.
- 4- Unknown affinities: This group includes dinoflagellate cysts that do not fall into any of the groups above.

7.1. Species List

7.1.1 *Division* Dinoflagellata

7.1.2 *Class* *Dinophyceae*

7.1.3 *Order* *Peridiniales*

7.1.4 *Dinogymnioid* Group

Alisogymnium euclaense (Cookson and Eisenack, 1970) Lentin and Vozzhennikova (1990)

Alisogymnium cerviculum (Cookson and Eisenack, 1970) Lentin and Vozzhennikova (1990)

Dinogymnium acuminatum (Evitt et al., 1967)

Dinogymnium cretaceum (Deflandre, 1936) Evitt et al. (1967)

Dinogymnium digchitus (Deflandre, 1936) Evitt et al. (1967)

Dinogymnium longicorne (Vozzhennikova, 1967) (Harland, 1973) emend. Lentin and Vozzhennikova, 1990

Dinogymnium nelsonense (Cookson, 1956) Evitt et al., 1967

Dinogymnium sibiricum (Cookson, 1956) Evitt et al., 1967

Dinogymnium sp.1

Dinogymnium sp.2

Yolkinigymnium expansum (Firth, 1993)

Yolkinigymnium lanceolatum (May, 1977) Lentin and Vozzhennikova (1990)

7.1.5 Gonyaulacoid Group

Achilleodinium sp.1

Achomosphaera ramulifera (Deflandre, 1937b) Evitt (1963)

Apteodinium fallax

Apteodinium cf. *A. granulatum* (Eisenack, 1958) emend. Sarjeant (1985); Lucas-Clark (1987)

Batiacasphaera reticulata (Davey, 1969a) Davey (1979)

Cannosphaeropsis sp.1

Carpatella cornuta (Grigorovich, 1969) emend. Fechner and Mohr (1986);

Damassa (1988)

Cerbia tabulata (Davey and Verdier, 1974) Below (1981)

Conosphaeridium striatoconum (Deflandre and Cookson, 1955) Cookson and Eisenack (1969)

Cordosphaeridium fibrospinum (Davey and Williams, 1966b) emend. Davey (1969b)

Cordosphaeridium? gracilis (Eisenack, 1954b) Davey and Williams, 1966b

Cordosphaeridium inodes (Klumpp, 1953) Eisenack (1963) emend. Morgenroth (1968); Sarjeant (1981); Lentin and Williams (1985)

Coronifera cf. *C. oceanica* (Cookson and Eisenack, 1958) emend. May (1980)

Cribroperidinium giuseppei (Morgenroth, 1966) Helenes (1984)

Cribroperidinium wetzelii (Lejeune-Carpentier, 1939) Helenes (1984)

Circulodinium distinctum (Deflandre and Cookson, 1955) Jansonius (1986)

Cyclonephelium compactum (Davey and Verdier, 1974)

Damassadinium californicum (Drugg, 1967) Fensome et al. (1993b)

Damassadinium fibrosum (Hultberg, 1985) Fensome et al. (1993)

Dinoflagellate sp.1

Disphaerogena carposphaeropsis (Wetzel, 1933b) emend. Sarjeant (1981)

Eisenackia crassitabulata (Deflandre and Cookson, 1955) emend. McLean (1973)

Exochosphaeridium bifidum (Clark and Verdier, 1967) Clarke et al. (1968) emend. Davey (1969b)

Florentinia perforata (Firth, 1993)

Glaphyrocysta cf. *G. reticulosa* (Gerlach, 1961) Stover and Evitt (1978)

Glaphyrocysta retiintexta (Cookson, 1965) Stover and Evitt (1978)

Glaphyrocysta expansa (Corradini, 1973) Roncaglia and Corradini (1997)

Glaphyrocysta perforata (Hultberg and Malmgren, 1985)

Hafniasphaera septata (Cookson and Eisenack, 1967b) Hansen (1977)

Hystrichosphaeridium tubiferum (Ehrenberg, 1838) Deflandre, 1937b emend.
Davey and Williams (1966b)

Impagidinium cristatum (May, 1980) Lentin and Williams (1981)

Impagidinium multiplex (Wall and Dale, 1968a) Lentin and Williams (1981)

Impagidinium cf. *I. patulum* (Wall, 1967) Stover and Evitt (1978)

Operculodinium centrocarpum (Deflandre and Cookson, 1955) Wall (1967)

Oligosphaeridium complex (White, 1842) Davey and Williams (1966b)

Operculodinium radiculatum (Smith, 1992)

Palynodinium grallator (Gocht, 1970a)

Palynodinium sp.1

Pterodinium cingulatum (Wetzel, 1933b) Below, 1981a

Rottnesia cf. *R. granulata* (Hultberg, 1985)

Spiniferites membranaceous (Rossignol, 1964) Sarjeant (1970)

Spiniferites ramosus (Ehrenberg, 1838) Mantell (1854)

Spiniferites ramosus subsp. reticulatus (Davey and Williams, 1966a) Lentin and
Williams (1973)

Spongodinium delitiense (Ehrenberg, 1838) Deflandre, 1936b emend. Lucas-
Clark, 1987

Tanyosphaeridium variecalamum (Davey and Williams, 1966b)

Tectatodonium rugulatum (Hansen, 1977) McMinn (1988)

Thalassiphora pelagica (Eisenack, 1954) Eisenack and Gocht (1960) emend.
Benedek and Gocht (1981)

Xenascus ceratiodes (Deflandre, 1937) Lentin and Williams (1973)

Ynezidinium pentahedrias (Damassa, 1979) Lucas-Clark and Helenes (2000)

7.1.6 Peridinioid Group

Alterbidinium acutulum (Wilson, 1967a) Lentin and Williams (1985) emend.
Khowaja-Ateequzzaman and Jain (1991)

Alterbidinium cf. A. circulum (Heilmann-Clausen, 1985) Lentin and Williams
(1989)

Alterbidinium cf. A. distinctum (Wilson, 1967b) Lentin and Williams (1985)

Andalusiella gabonensis (Stover and Evitt, 1978) Wrenn and Hart (1988)

Cerodinium diebelii (Alberti, 1959) Lentin and Williams (1987)

Cerodinium diebelii subsp. *rigidum* (May, 1980) Lentin and Williams (1987)

Cerodinium leptodermum (Vozzhennikova, 1963) Lentin and Williams (1987)

Cerodinium pannuceum (Stanley, 1965) Lentin and Williams (1987)

Cerodinium speciosum (Alberti, 1959) Lentin and Williams (1987)

Chatangiella ditissima (McIntyre, 1975) Lentin and Williams (1976)

Chatangiella granulifera (Manum, 1963) Lentin and Williams (1976)

Chatangiella micrachanta (Cookson and Eisenack, 1960) Lentin and Williams
(1976)

Deflandrea galeata (Lejeune-Carpentier, 1946); Lentin and Williams (1973)
emend. Lejeune-Carpentier and Sarjeant (1981)

Diconodinium psilatatum (Morgan, 1977)

Isabelidinium bakeri (Deflandre and Cookson, 1955) Lentin and Williams (1977)

Isabelidinium cooksoniae (Alberti, 1959) Lentin and Williams (1977)

Lejeunecysta sp.1

Magallanesium sp. cf. *M. essoii* (Cookson and Eisenack, 1967a) Quattrocchio and Sarjeant (2003)

Magallanesium densispinatum (Stanley, 1965) Quattrocchio and Sarjeant (2003)

Manumiella cretacea (Cookson, 1956) Bujak and Davies (1983)

Manumiella druggii (Stover, 1974) Bujak and Davies (1983)

Manumiella seymourensis (Askin, 1999)

Paleocystodinium australinum (Cookson and Eisenack, 1965) Lentin and Williams (1976) emend. Malloy (1972)

Paleocystodinium golzowense (Alberti, 1961)

Phelodinium africanum (Biffi and Grignani, 1983)

Phelodinium magnificum (Stanley, 1965) Stover and Evitt (1978)

Pierceites pentagonus (May, 1980) Habib and Drugg (1987)

Senegalinium bicavatum (Jain and Millepied, 1973)

Senegalinium laevigatum (Malloy, 1972) Bujak and Davies (1983)

Senegalinium microgranulatum (Stanley, 1965) Stover and Evitt (1978)

Senegalinium obscurum (Drugg, 1967) Stover and Evitt (1978)

Senegalinium pallidum (Lucas-Clark, 2006)

Senegalinium simplex (Lucas-Clark, 2006)

Senegalinium sp.1

Spinidinium ornatum (May, 1980)

Trithyrodinium evittii (Drugg, 1967)

7.1.7 Acritarch

Fromea fragilis (Cookson and Eisenack, 1962)

Acritarch sp.1

7.1.8 Angiosperm Pollen

Aquilapollenites (Rouse, 1957) Funkhouser (1961)

Wodehouseia spinata (Stanley, 1961)

7.2 Systematics

7.2.1 Division *Dinoflagellata*

7.2.2 Class *Dinophyceae*

7.2.3 Order *Peridiniales*

7.2.4 *Dinogymnioid* Group

7.2.4.1 Genus *Dinogymnium* (Evitt et al., 1967)

7.2.4.1.1 *Dinogymnium* sp. 1 (Plate 1, Figure 1)

Dimensions: Body width: 34.0 μm , length: 56.7 μm , epitheca: 35.9 μm ,
hypotheca: 28.3 μm .

Description: Cyst elongated, epicyst and hypocyst are of the same size. Epitheca is conical with a rounded apex, and has longitudinal ridges. Hypotheca is conical, slightly rounded at the antapex, and lacks longitudinal ridges. Paracingulum laevorotatory displaced about one cingulum width. Archeopyle is apical.

Comparison: This specimen is similar to *Dinogymnium acuminatum*, in having an elongated shape with narrow apex and antapex, but differs in lacking longitudinal ridges on the hypotheca. Also, the antapex is narrower than *D. acuminatum* and forms slight “shoulders” close to the tip. This specimen is also very similar to *Dinogymnium aerlicum*, but *D. aerlicum* has a pointed tip on the antapex.

7.2.4.1.2 *Dinogymnium* sp. 2 (Plate 1, Figure m)

Dimensions: Body height: 40.2 μm , Cyst body width: 34.1 μm . Cingulum width: 5.7 μm . Total specimens measured: 1

Description: Small, rounded dinogymnioid cyst. Epicyst and hypocyst are about the same size. Both epitheca and hypotheca are broadly rounded and they are separated by a wide paracingulum. Archeopyle apical. Autophragm granular on both epitheca and hypotheca, as well as on paracingulum. Longitudinal ridges on autophragm very distinct.

Comparison: This species resembles *Dinogymnium cretaceum*, but differs by having more elongated and pronounced longitudinal ridges.

Previously reported occurrences:

Firth (1987): Maastrichtian of Georgia (As *Dinogymnium* sp.C)

7.2.5 *Gonyaulacoid* Group

7.2.5.1 Genus *Achilleodinium* (Eaton, 1976)

7.2.5.1.1 *Achilleodinium* sp.1 (Plate 2, Figure b-c)

Dimensions: Body width: 58.4 μm , length: 47.8 μm . Total number of specimens measured: 1.

Description: Subspherical, skolochorate gonyaulacoid cyst. Processes are penitabular, wide, short and closed. Periphragm lightly granulate. Archeopyle precingular (?).

7.2.5.2 Genus *Apteodinium* (Eisenack, 1958)

7.2.5.2.1 *Apteodinium* cf. *A. granulatum* (Plate 2, Figure e-h) (Eisenack, 1958)

Dimensions: Body length: 59.0-64.0 μm (mean: 62.4 μm , std dev. 2.2 μm , n=3), cyst body width: 59.0-64.0 μm (mean: 62.7 μm , std. dev. 3.1 μm , n=3), apical horn length: 6.0-8.0 μm (mean: 6.9 μm , std. dev. 1.1, n=2). Total number of specimens measured: 3. Autophragm thickness: 3.8 μm .

Description: Acavate, subspherical, gonyaulacoid cyst with short pointed apical horn. Autophragm thick ($> 3\mu\text{m}$), and densely granulated. No indication of paratabulation. However, lightly smooth areas on the cyst wall present. Archeopyle is precingular, rounded, operculum free.

Discussion: These specimens, overall bear all the descriptive features of *Apteodinium granulatum*, which was described from Aptian sediments by Eisenack (1958). The youngest occurrence for this species was reported from Santonian sediments

by Scott et al. (2012). Previously reported occurrences of *A. granulatum* are older than Maastrichtian, and for this reason these specimens are referred to as *A. cf. A. granulatum*.

7.2.5.3 Genus *Cannosphaeropsis* (Wetzel, 1933)

7.2.5.3.1 *Cannosphaeropsis* sp. 1 (Plate 2, Figure 1; Plate 3, Figure a-b)

Dimensions: Body width: 32.0-50.0 μm (mean: 40.9 μm , std dev. 11.8 μm , n=2), body length: 37.0-54.0 μm (mean: 45.1 μm , std dev. 11.3 μm , n=3), processes: 15.0-18.0 μm . Total number of specimens measured: 2. Cyst wall thickness: 0.4 μm .

Description: Chorate, subspherical, gonyaulacoid cyst bearing gonal and intergonal processes, connecting with trabeculae immediately below the trifurcate ends. Autophragm is thin (< 1 μm) and microreticulate. Processes are mostly trifurcate, occasionally bifurcate. Processes and trabeculae are vesicular. Trabeculae forming between processes is perforated. Archeopyle is precingular.

Comparison: These species resemble *Cannosphaeropsis franciscana* and *Cannosphaeropsis utinensis*. *Cannosphaeropsis franciscana* is distinguished by having a smooth autophragm, incomplete development of paratabulation as indicated by the trabeculae and by the presence of an apical projection. However, my species lacks of an apical projection, and have a microreticulate autophragm as well as vesicular processes and trabeculae. *Cannosphaeropsis utinensis* is also different than my species by lacking microreticulate and vesicular structures.

Previously reported occurrences:

Evitt (1973): Maastrichtian of Texas (As *Cannosphaeropsis cf.aff. C.utinensis*)

7.2.5.4 Genus *Coronifera* (Cookson and Eisenack, 1958)

7.2.5.4.1 *Coronifera cf. C. oceanica* (Plate 2, Figure i-j) (Cookson and Eisenack, 1958)
emend. May (1980)

Dimensions: Body width: 48.5 μm , length: 57.6 μm . Apical processes: 15.2 μm ,
antapical process: 18.2 μm . Total specimens measured: 1.

Description: Chorate, spherical, gonyalucoid cyst bearing nontabular processes.
Processes are smooth, conical. Endophragm is smooth, periphragm forms the processes.
Archeopyle type is not clear.

Discussion: This specimen is similar to the emended description of *Coronifera oceanica* reported in May (1980), by having a spherical body shape and smooth, conical, non-tabular processes. However, the apical nipple and denticulate large antapical process margin are not observed.

7.2.5.5 Genus *Impagidinium* (Stover and Evitt, 1978)

7.2.5.5.1 *Impagidinium cf. I. patulum* (Plate 5, Figure e) (Wall, 1967) Stover and Evitt
(1978)

Dimensions: Body width: 62.3 μm , length: 68.0 μm . Total specimens measured:
1.

Description: Proximate, circular, gonyaulacoid cyst bearing parasutural ridges with low septa. Periphragm lightly granulate. My specimens are poorly preserved and it is hard to discern their exact paratabulation.

7.2.5.6 Genus *Palynodinium* (Gocht, 1970)

7.2.5.6.1 *Palynodinium* sp. 1 (Plate 6, Figure g)

Dimensions: Body width: 100.1 μm , length: 71.3 μm . Pericoel with processes: 17.1 μm . Total number of specimens measured: 1

Description: Skolochorate, dorsoventrally compressed gonyaulacoid cyst with lenticular shape. Endophragm and periphragm thin ($<1 \mu\text{m}$). Two small pericoels developed on left and right sides of ventral surface. Furcated processes emanate from the surface of the pericoels. Processes length is varied. Endophragm smooth and periphragm lightly granular. Archeopyle apical, operculum free.

Discussion: This species closely resembles *Palynodinium grillator* (Gocht, 1970), but differs by lacking parasutural features, as well as smaller less- developed pericoels. This species is also smaller in size than *P. grillator*.

7.2.5.7 Genus *Rottnestia* (Cookson and Eisenack, 1961)

7.2.5.7.1 *Rottnestia* cf. *R. granulata* (Plate 6, Figure h) (Hultberg, 1985)

Dimensions: Body width: 26.5 μm , length: 39.7 μm . Total specimens measured: 1.

Description: Bicavate, elongated, gonyaulacoid cyst. Periphragm lightly granular. Apical process elongate, with bifurcate tip. Periphragm forms an antapical pericoel that

emanates from the gonal sutures. Archeopyle precingular. Paracingulum is represented by two longitudinal ridges. Small processes occur at gonal points of paracingular paraplates.

Discussion: This specimen is similar to *Rottnestia granulata* reported in Hultberg (1985), but differs by having a longer apical process and shorter paracingular processes.

7.2.5.8 Dinoflagellate sp. 1 (Plate 4, Figure f)

Dimensions: Body width: 44.0 μm , length: 49.2 μm . Total specimens measured: 1.

Description: Proximochorate, ovoidal, gonyaulacoid cyst. Periphragm granular. Apical archeopyle. Parasutural ridges present. Processes are short, wide, tubular. Paracingulum is not evident, except for short paracingular processes.

7.2.6 Peridinioid Group

7.2.6.1 Genus *Lejeunecysta* (Artzner and Dörhöfer, 1978)

7.2.6.1.1 *Lejeunecysta* sp. 1 (Plate 10, Figure g)

Dimensions: Body width: 107.6 μm , length: 119.8 μm . Total specimens measured: 1.

Description: Proximate, single walled, pentagonal shaped peridinioid cyst. Apex is sub-triangular with truncated apical horn. Two antapical horns well developed, slightly rounded end. Paracingulum is defined by two parallel lines that which have

small regularly spaced spines. Autophragm is folded, lightly granulate. Granulate pattern is denser close to the paracingulum. Archeopyle is intercalary.

Discussion: This specimen is similar to *Lejeunecysta cinctoria* (Bujak et al., 1980). It differs by not having pronounced spines on the dorsal part of the paracingulu, and lacks spines on apex and antapex. Also, this specimen is larger than *L. cinctoria*.

7.2.6.2 Genus *Senegalinium* (Jain and Millepied, 1973)

7.2.6.2.1 *Senegalinium* sp. 1 (Plate 12, Figure i-j)

Dimensions: Body width: 37.9 μm , length: 40.2 μm . Total number of specimens measured: 1

Description: Proximate, elongated peridinioid cyst. Epitheca is subtriangular. Apex is slightly rounded. Antapex forms two (?) antapical horns. Archeopyle is intercalary. Paracingulum faintly present. Periphragm granulate.

Discussion: This specimen is similar to *Senegalinium microgranulatum*, but it differs by having shorter apical and antapical horns, and the periphragm is more densely granular than *S. microgranulatum*.

8. CONCLUSIONS

Palynological study of the Maastrichtian Neylandville and Corsicana Formation, and the Danian Kincaid Formation revealed abundant species of dinoflagellates and terrestrial palynomorphs. Stratigraphically important dinoflagellate species datums divide the section into three intervals. Accordingly, the Neylandville Formation is early Maastrichtian age, the Corsicana Formation is of late Maastrichtian age and the Kincaid Formation is of Danian age.

Relative abundance of dinoflagellate cysts correlating with palynofacies indicate two intervals of terrestrial influence within the Maastrichtian, within the Neylandville Formation and the middle of the Corsicana Formation. Marine influence is dominant at the base and the top of the Corsicana Formation. Acme peaks of *Exochosphaeridium* spp., *Glaphyrocysta* spp. and *Spiniferites* spp. in the Brazos River section correlates well with abundance peaks of these species in the Austin section, indicating regional peak abundances of the species.

Cooling in sea surface temperatures occurred from the early Maastrichtian to the K-Pg boundary in the Brazos River section. Low M/T ratios correlate well with high P/G ratios indicating increases in paleoproductivity in the Corsicana and Kincaid formations.

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APPENDIX 1

Occurrence and optical details of palynomorphs in studied samples. The first column shows the taxon name. The next column shows illustrations for the taxon. The locations for each taxa listed as a combination of sample name, slide number and coordinates on following columns. Specimen locations on slides were given as right (R) and above (U) in millimeters to lower right corner of the cover slide. Last column lists the type of illumination used while photographing the specimens: pl: plain light; ph: phase contrast.

| Taxon | Plate- Figure | Sample | Slide | Coordinates | Lens Type |
|-------------------------------------|-----------------------------------|---------------|--------------|--------------------|------------------|
| DINOFLAGELLATE CYSTS | | | | | |
| <i>Achilleodinium sp.1</i> | Plate-2-fig.b-c | RBS-J | 1 | 3.3x75.2 | pl |
| <i>Achomospaera ramulifera</i> | Plate-2-fig.a | BC-1 | 1 | 17.2x69.0 | ph |
| <i>Alisogymnium euclaense</i> | Plate-1-fig.a | BC-4 | 1 | 13.0x70.3 | pl |
| <i>Alisogymnium cerviculum</i> | Plate-1-fig.b-c | BC-11 | 1 | 17.8x74.5 | pl |
| <i>Alterbidinium acutululum</i> | Plate-7-fig.h-i | BN-21 | 1 | 9.0x67.6 | ph |
| <i>Alterbidinium cf. A.circulum</i> | Plate-7-fig.j-k | RBS-Z | 2 | 29.7x69.0 | ph |
| <i>Andalusiella gabonensis</i> | Plate-8-fig.a | BC-11 | 1 | 17.0x70.6 | pl |
| <i>Apteodinium fallax</i> | Plate-2-fig.d | RBS-W | 1 | 1.3x66.3 | pl |
| <i>Apteodinium cf.A.granulatum</i> | Plate-2-fig.e-h | BN-21 | 1 | 10.3x69.2 | pl |
| <i>Batiacasphaera reticulata</i> | Plate-2-fig.k | BN-19 | 1 | 26.5x69.9 | ph |
| <i>Cannosphaeropsis sp.1</i> | Plate-2-fig.l; Plate-3-fig.a-b | BC-4 | 1 | 9.6x71.6 | pl |
| <i>Carpatella cornuta</i> | Plate-3-fig.c-d | RBS-J | 1 | 5.5x84.4 | pl |
| <i>Cerbia tabulata</i> | Plate-3-fig.e-f | BN-19 | 1 | 3.6x81.7 | pl |

| Taxon | Plate- Figure | Sample | Slide | Coordinates | Lens Type |
|---|----------------------|---------------|--------------|--------------------|------------------|
| <i>Cerodinium diebelii</i> | Plate-8-fig.b-c | RBS-J | 1 | 11.0x75.9 | pl |
| <i>Cerodinium diebelii subsp. rigidum</i> | Plate-8-fig.d-g | BC-3 | 1 | 12.8x71.7 | pl |
| <i>Cerodinium leptodermum</i> | Plate-8-fig.f | RBS-J | 1 | 28.0x79.6 | pl |
| <i>Cerodinium pannuceum</i> | Plate-8-fig.h | BC-2 | 1 | 6.3x64.8 | pl |
| <i>Cerodinium speciosum</i> | Plate-9-fig.a | RBS-J | 1 | 17.0x82.4 | pl |
| <i>Chatangiella ditissima</i> | Plate-9-fig.b-c | BN-19 | 1 | 8.7x67.6 | ph |
| <i>Chatangiella granulifera</i> | Plate-9-fig.f-g | BN-19 | 1 | 25.0x84.3 | pl |
| <i>Chatangiella micracantha</i> | Plate-9-fig.d-e | BN-19 | 1 | 18.2x72.2 | ph |
| <i>Circulodinium distinctum</i> | Plate-3-fig.h | BC-14 | 1 | 1.0x72.8 | ph |
| <i>Conosphaeridium striatoconum</i> | Plate-3-fig.g | BC-4 | 1 | 8.4x79.4 | pl |
| <i>Cordosphaeridium fibrospinosum</i> | Plate-3-fig.i | BC-14 | 1 | 20.1x71.4 | pl |
| <i>Cordosphaeridium? gracilis</i> | Plate-3-fig.k | RBS-W | 1 | 6.0x73.2 | pl |
| <i>Cordosphaeridium inodes</i> | Plate-3-fig.j | BC-16 | 2 | 22.3x69.6 | pl |
| <i>Coronifera cf. C.oceanica</i> | Plate-2-fig.i-j | BC-14 | 2 | 13.0x69.5 | pl |
| <i>Cribroperidinium giuseppeii</i> | Plate-3-fig.l | RBS-J | 1 | 17.4x78.8 | pl |
| <i>Cribroperidinium wetzelii</i> | Plate-4-fig.a | BC-4 | 1 | 29.8x78.3 | pl |
| <i>Cyclonephelium compactum</i> | Plate-4-fig.b | BC-20 | 1 | 8.7x81.2 | ph |
| <i>Damassidinium californicum</i> | Plate-4-fig.c | RBS-J | 1 | 23.7x74.4 | pl |
| <i>Damassadinium fibrosum</i> | Plate-4-fig.d | BC-18 | 1 | 2.9x69.4 | ph |
| <i>Deflandrea galeata</i> | Plate-9-fig.h-i | BN-19 | 2 | 12.4x66.4 | pl |
| <i>Diconodinium psilatium</i> | Plate-9-fig.j | BC-18 | 1 | 23.6x80.5 | ph |
| <i>Dinoflagellate sp.1</i> | Plate-4-fig. f | BN-20 | 2 | 17.0x73.4 | ph |
| <i>Dinogymnium acuminatum</i> | Plate-1-fig.d | BC-4 | 1 | 12.9x65.1 | pl |
| <i>Dinogymnium cretaceum</i> | Plate-1-fig.d-e | BC-18 | 1 | 5.2x69.9 | pl |
| <i>Dinogymnium digitus</i> | Plate-1-fig.g-h | BN-19 | 2 | 2.2x72.3 | pl |
| <i>Dinogymnium longicorne</i> | Plate-1-fig.i | BC-17 | 1 | 6.8x68.5 | pl |

| Taxon | Plate- Figure | Sample | Slide | Coordinates | Lens Type |
|---------------------------------------|----------------------|---------------|--------------|--------------------|------------------|
| <i>Dinogymnium nelsonense</i> | Plate-1-fig.j | BC-1 | 1 | 15.2x65.4 | pl |
| <i>Dinogymnium sibiricum</i> | Plate-1-fig.k | BC-18 | 1 | 5.2x65.7 | pl |
| <i>Dinogymnium sp.1</i> | Plate-1-fig.l | BC-18 | 2 | 2.5x68.9 | pl |
| <i>Dinogymnium sp.2</i> | Plate-1-fig.m | RBS-W | 1 | 13.6x68.2 | pl |
| <i>Disphaerogena carposphaeropsis</i> | Plate-4-fig.e | BC-14 | 1 | 12.8x70.4 | ph |
| <i>Eisenackia crassitabulata</i> | Plate-4-fig.g | RBS-J | 1 | 8.9x76.0 | pl |
| <i>Exochosphaeridium bifidum</i> | Plate-4-fig.h | BC-16 | 1 | 14.9x77.4 | ph |
| <i>Florentinia perforata</i> | Plate-4-fig.i | BC-14 | 1 | 5.5x64.5 | ph |
| <i>Glaphyrocysta cf.G.reticulosa</i> | Plate-4-fig.j | BC-14 | 1 | 19.9x72.7 | pl |
| <i>Glaphyrocysta expansa</i> | Plate-4-fig.k | BC-14 | 1 | 1.5x72.0 | pl |
| <i>Glaphyrocysta perforata</i> | Plate-5-fig.a | RBS-F | 1 | 3.0x71.5 | pl |
| <i>Glaphyrocysta retiintexta</i> | Plate-5-fig.c | BC-4 | 1 | 14.6x80.7 | ph |
| <i>Hafniasphaera spp.</i> | Plate-5-fig.b | BC-20 | 2 | 25.2x73.5 | pl |
| <i>Hystrichosphaeridium tubiferum</i> | Plate-5-fig.d | BBC-3 | 1 | 14.8x71.9 | pl |
| <i>Impagidinium cf. I.patulum</i> | Plate-5-fig.e | RBS-J | 1 | 21.9x65.6 | ph |
| <i>Impagidinium cristatum</i> | Plate-5-fig.f-g | BN-21 | 1 | 0.7x69.1 | pl |
| <i>Impagidinium multiplex</i> | Plate-5-fig.h-j | RBS-J | 1 | 10.5x75.0 | pl |
| <i>Isabelidinium bakeri</i> | Plate-9-fig.k | RBS-Z | 1 | 12.7x69.0 | ph |
| <i>Isabelidinium cooksoniae</i> | Plate-10-fig.a-d | BN-19 | 2 | 7.0x72.3 | ph |
| <i>Isabelidinium sp.1</i> | Plate-10-fig.e-f | BN-19 | 2 | 21.8x72.4 | pl |
| <i>Lejeunecysta sp.1</i> | Plate-10-fig.g | RBS-F | 1 | 8.1x70.9 | pl |
| <i>Magallanesium cf. M.essoii</i> | Plate-10-fig.h | RBS-Z | 1 | 12.6x68.5 | pl |
| <i>Magallanesium densispinatum</i> | Plate-10-fig.i-j | RBS-J | 1 | 39.4x56.09 | pl |
| <i>Manumiella druggii</i> | Plate-10-fig.k-l | RBS-F | 1 | 25.7x75.3 | pl |
| <i>Manumiella seymourensis</i> | Plate-11-fig.a-c | BC-11 | 1 | 5.9x69.9 | ph |
| <i>Oligosphaeridium complex</i> | Plate-6-fig.b | BC-15 | 1 | 28.5x77.8 | ph |

| Taxon | Plate- Figure | Sample | Slide | Coordinates | Lens Type |
|--|----------------------|---------------|--------------|--------------------|------------------|
| <i>Operculodinium centrocarpum</i> | Plate-6-fig.c | BC-15 | 1 | 27.8x66.5 | pl |
| <i>Operculodinium radiculatum</i> | Plate-6-fig.d | BN-21 | 1 | 3.7x73.5 | pl |
| <i>Palaeocystodinium australinum</i> | Plate-11-fig.d | BC-11 | 1 | 21.7x69.9 | pl |
| <i>Palaeocystodinium golzowense</i> | Plate-11-fig.e-f | BC-4 | 1 | 21.1x65.8 | ph |
| <i>Palynodinium grallator</i> | Plate-6-fig.e | BC-18 | 1 | -0.8x69.0 | ph |
| <i>Palynodinium sp.1</i> | Plate-6-fig.g | BC-1 | 1 | 17.1x71.5 | pl |
| <i>Phelodinium africanum</i> | Plate-11-fig.g | BC-11 | 1 | 27.7x75.2 | ph |
| <i>Phelodinium magnificum</i> | Plate-11-fig.h | BC-11 | 1 | 27.9x76.8 | pl |
| <i>Pierceites pentagonus</i> | Plate-11-fig.i | BC-2 | 1 | 5.6x72.3 | pl |
| <i>Pterodinium cingulatum</i> | Plate-6-fig.i-j | BC-15 | 2 | 20.2x78.2 | pl |
| <i>Rottnestia cf. R.granulata</i> | Plate-6-fig.h | RBS-J | 1 | 26.0x72.1 | pl |
| <i>Senegalinium bicavatum</i> | Plate-12-fig.a | BN-21 | 1 | 7.4x66.7 | pl |
| <i>Senegalinium laevigatum</i> | Plate-12-fig.b | BC-15 | 1 | 7.6x67.0 | pl |
| <i>Senegalinium microgranulatum</i> | Plate-12-fig.c | RBS-J | 1 | 9.3x68.2 | ph |
| <i>Senegalinium obscurum</i> | Plate-12-fig.d | BC-15 | 1 | 8.2x68.9 | ph |
| <i>Senegalinium pallidum</i> | Plate-12-fig.e | RBS-J | 1 | 13.5x68.0 | ph |
| <i>Senegalinium sp.1</i> | Plate-12-fig.i-j | BN-19 | 2 | 16.9x71.8 | ph |
| <i>Senegalinium simplex</i> | Plate-12-fig.f | BC-16 | 2 | 2.3x67.4 | pl |
| <i>Spinidinium ornatum</i> | Plate-12-fig.g-h | BN-19 | 2 | 11.1x65.7 | pl |
| <i>Spiniferites membranaceus</i> | Plate-6-fig.f | BC-18 | 1 | 2.0x66.3 | pl |
| <i>Spiniferites ramosus</i> | Plate-6-fig.k | BC-18 | 1 | 3.1x69.2 | pl |
| <i>Spiniferites ramosus subsp. reticulatus</i> | Plate-6-fig.l | BC-18 | 1 | 1.8x69.2 | pl |
| <i>Spongodinium delitiense</i> | Plate-7-fig.a-b | BC-17 | 1 | 14.1x67.3 | pl |
| <i>Tanyosphaeridium variecalamum</i> | Plate-7-fig.c | BC-1 | 1 | 5.9x70.0 | ph |
| <i>Tectatodinium rugulatum</i> | Plate-7-fig.d | RBS-W | 1 | 21.6x72.3 | pl |
| <i>Thalassiphora pelagica</i> | Plate-7-fig.e | BC-15 | 1 | 19.5x75.8 | pl |

| Taxon | Plate- Figure | Sample | Slide | Coordinates | Lens Type |
|-----------------------------------|----------------------|---------------|--------------|--------------------|------------------|
| <i>Trithyrodinium evittii</i> | Plate-12-fig.l-m | BC-10 | 1 | -0.8x79.6 | ph |
| <i>Xenascus ceratioides</i> | Plate-7-fig.f-g | BN-21 | 1 | 22.9x67.6 | pl |
| <i>Ynezinidinium pentahedrias</i> | Plate-5-fig.k-l | RBS-W | 1 | 17.3x72.8 | pl |
| | Plate-6-fig.a | | | | |
| <i>Yolkinigymnium expansum</i> | Plate-1-fig.n | RBS-A | 2 | 7.0x69.4 | pl |
| <i>Yolkinigymnium lanceolatum</i> | Plate-1-fig.o | BC-1 | 1 | 9.1x72.7 | pl |
| ACRITARCH | | | | | |
| <i>Fromea fragilis</i> | Plate-13-fig.f | BC-4 | 1 | 0.8x67.9 | pl |
| POLLEN AND SPORES | | | | | |
| <i>Wodehousia spinata</i> | Plate-13-fig.a | BC-4 | 1 | 9.7x66.7 | ph |
| <i>Tricolporate spore</i> | Plate-13-fig.b | BC-18 | 1 | 8.4x66.5 | pl |
| <i>Ephedripites sp.</i> | Plate-13-fig.c | BC-18 | 1 | 3.3x75.9 | pl |
| <i>Periporate pollen</i> | Plate-13-fig.d | BC-18 | 1 | 25.0x72.0 | pl |
| <i>Foraminifera lining</i> | Plate-13-fig.e | BC-18 | 1 | 21.9x82.7 | pl |

APPENDIX 2

This appendix includes illustrations of palynomorphs in the studied interval.

Plate illustrations follow the systematic listing of specimens.

PLATE 1

Figure

- a. *Alisogymnium euclaense* (dorsal view).
- b. *Alisogymnium cerviculum* (apical archeopyle in focus)
- c. *Alisogymnium cerviculum* (ventral view)
- d. *Dinogymnium acuminatum* (ventral view)
- e. *Dinogymnium cretaceum* (apical archeopyle in focus)
- f. *Dinogymnium cretaceum* (ventral view)
- g. *Dinogymnium digitus* (epicyst in focus)
- h. *Dinogymnium digitus* (hypocyst in focus)
- i. *Dinogymnium lognicorne* (ventral view)
- j. *Dinogymnium nelsonense* (dorsal view)
- k. *Dinogymnium sibiricum* (dorsal view)
- l. *Dinogymnium sp.1* (dorsal view- apical archeopyle in focus)
- m. *Dinogymnium sp.2* (dorsal view)
- n. *Yolkinigymnium expansum* (unknown view)
- o. *Yolkinigymnium lanceolatum* (unknown view)

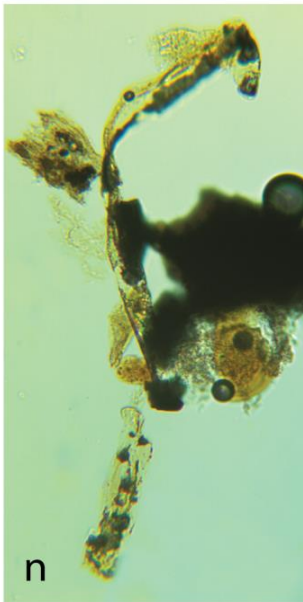
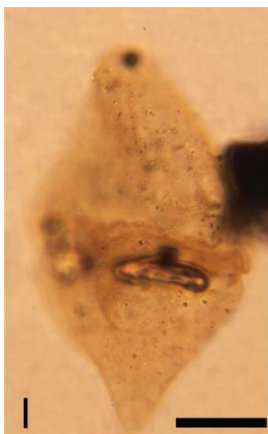
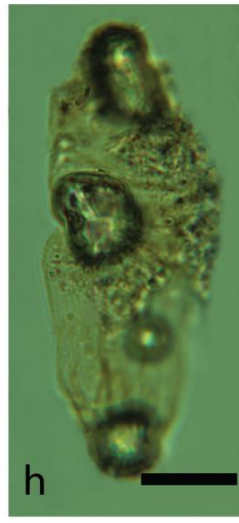
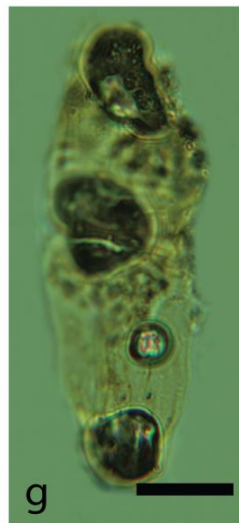
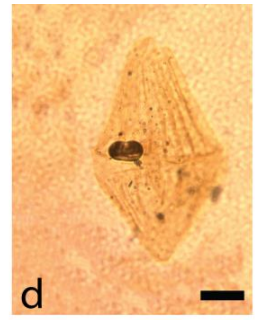
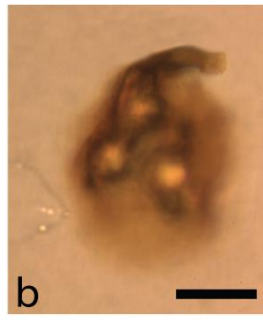


PLATE 2

Figure

- a. *Achomosphaera ramulifera*
- b. *Achilleodinium* sp.1 (archoeople in focus)
- c. *Achilleodinium* sp.1
- d. *Apteodinium fallax*
- e. *Apteodinium* cf.*A.granulatum* (dorsal view)
- f. *Apteodinium* cf.*A.granulatum* (close up to periphragm)
- g. *Apteodinium* cf.*A.granulatum* (archoeople in focus)
- h. *Apteodinium* cf.*A.granulatum* (note the reduced apical horn)
- i. *Coronifera* cf.*C.oceanica*
- j. *Coronifera* cf.*C.oceanica*
- k. *Batiacasphaera reticulata* (apical archoeople in focus)
- l. *Cannosphaeropsis* sp.1

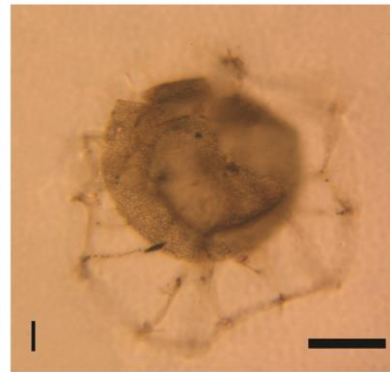
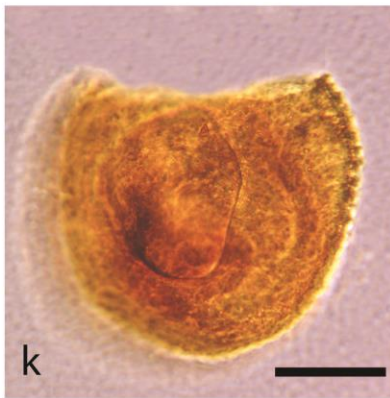
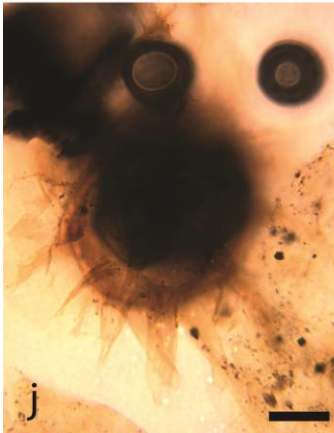
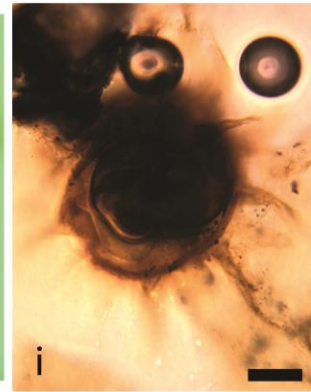
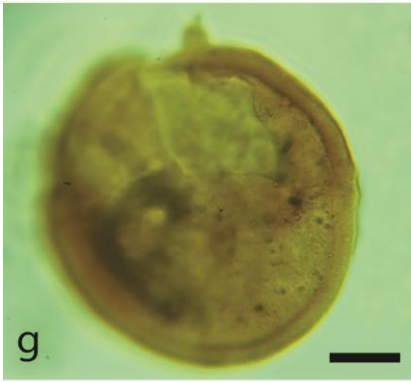
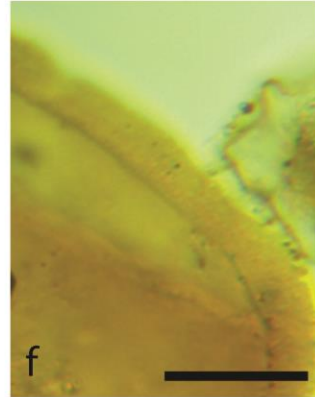
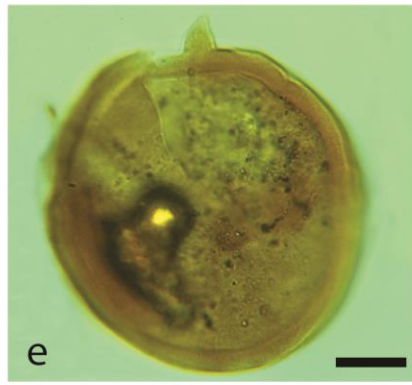
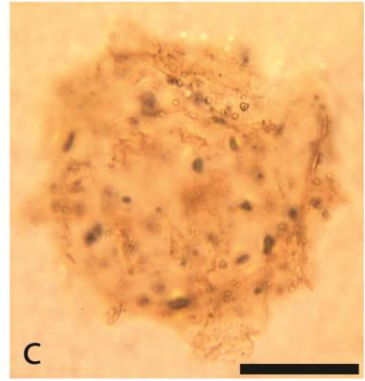
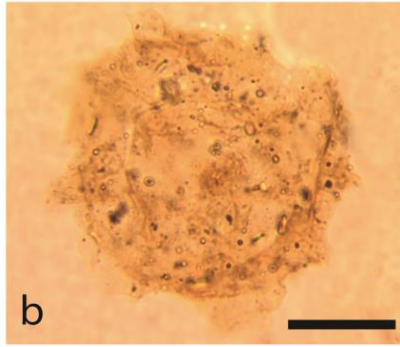
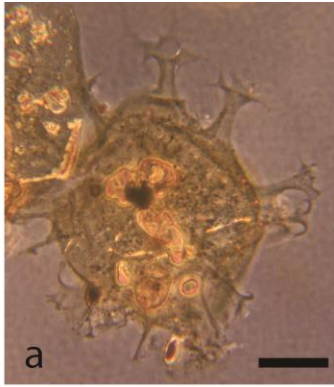


PLATE 3

Figure

- a. *Cannosphaeropsis sp.1* (archeopyle in focus)
- b. *Cannosphaeropsis sp.1* (processes with trabecula in focus)
- c. *Carpetalla cornuta* (apical horn in focus)
- d. *Carpetalla cornuta* (archeopyle in focus, note the antapical horn)
- e. *Cerbia tabulata*
- f. *Cerbia tabulata* (apical archeopyle in focus)
- g. *Conosphaeridium striatoconum*
- h. *Circulodinium distinctum*
- i. *Cordosphaeridium fibrospinosum*
- j. *Cordosphaeridium inodes*
- k. *Cordosphaeridium? gracilis*
- l. *Cribroperidinium giuseppi* (archeopyle in focus)

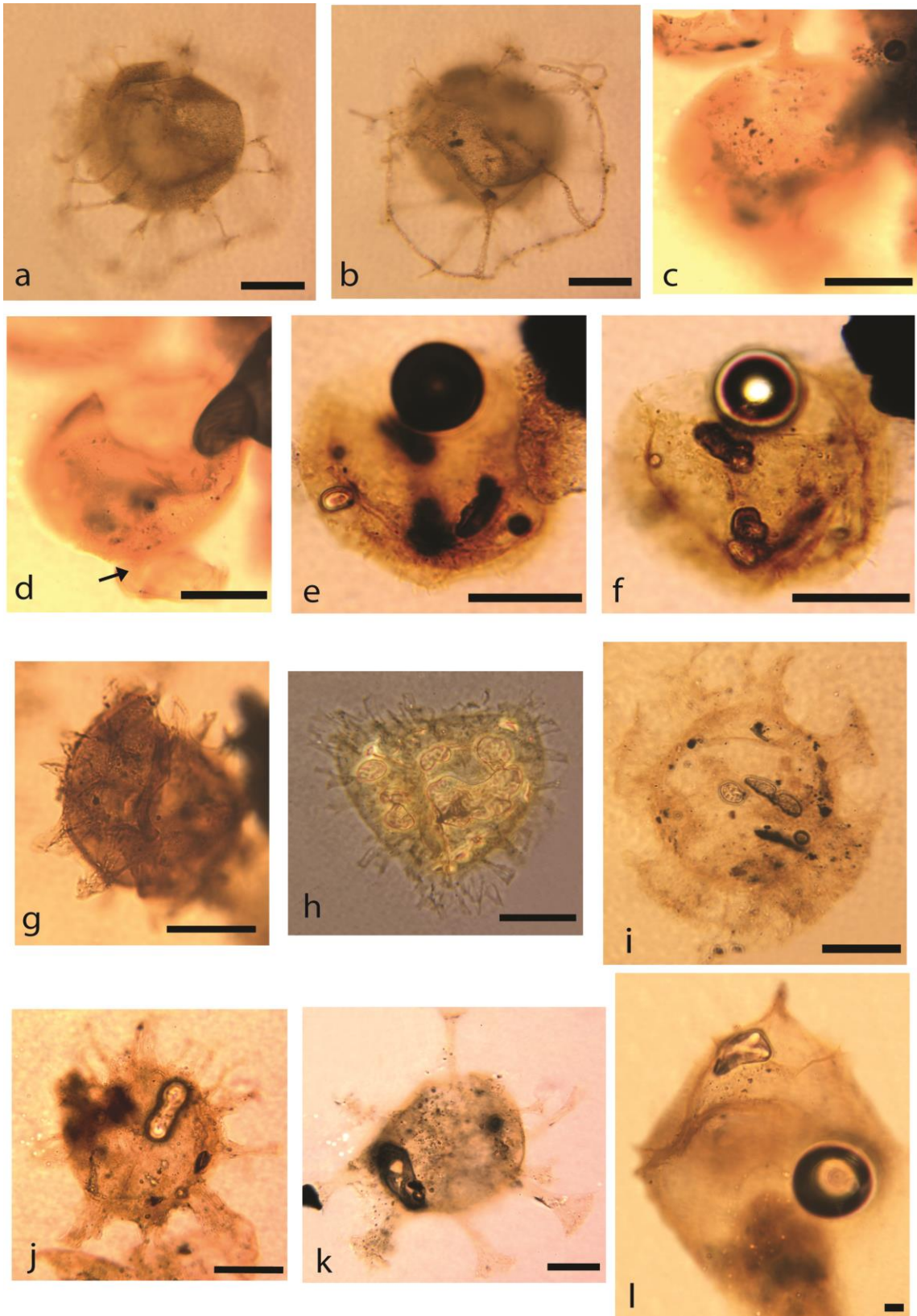


PLATE 4

Figure

- a. *Cribroperidinium wetzelii*
- b. *Cyclonephelium compactum* (archeopyle in focus)
- c. *Damassadinium californicum* (epicyst in focus)
- d. *Damassadinium fibrosum*
- e. *Disphaerogena carposphaeropsis* (dorsal view)
- f. *Dinoflagellate sp.1*
- g. *Eisenackia crassitabulata*
- h. *Exochosphaeridium bifidum*
- i. *Florentinia perforata* (archeopyle in focus)
- j. *Glaphyrocysta cf. G. reticulata* (archeopyle in focus)
- k. *Glaphyrocysta expansa* (archeopyle in focus)

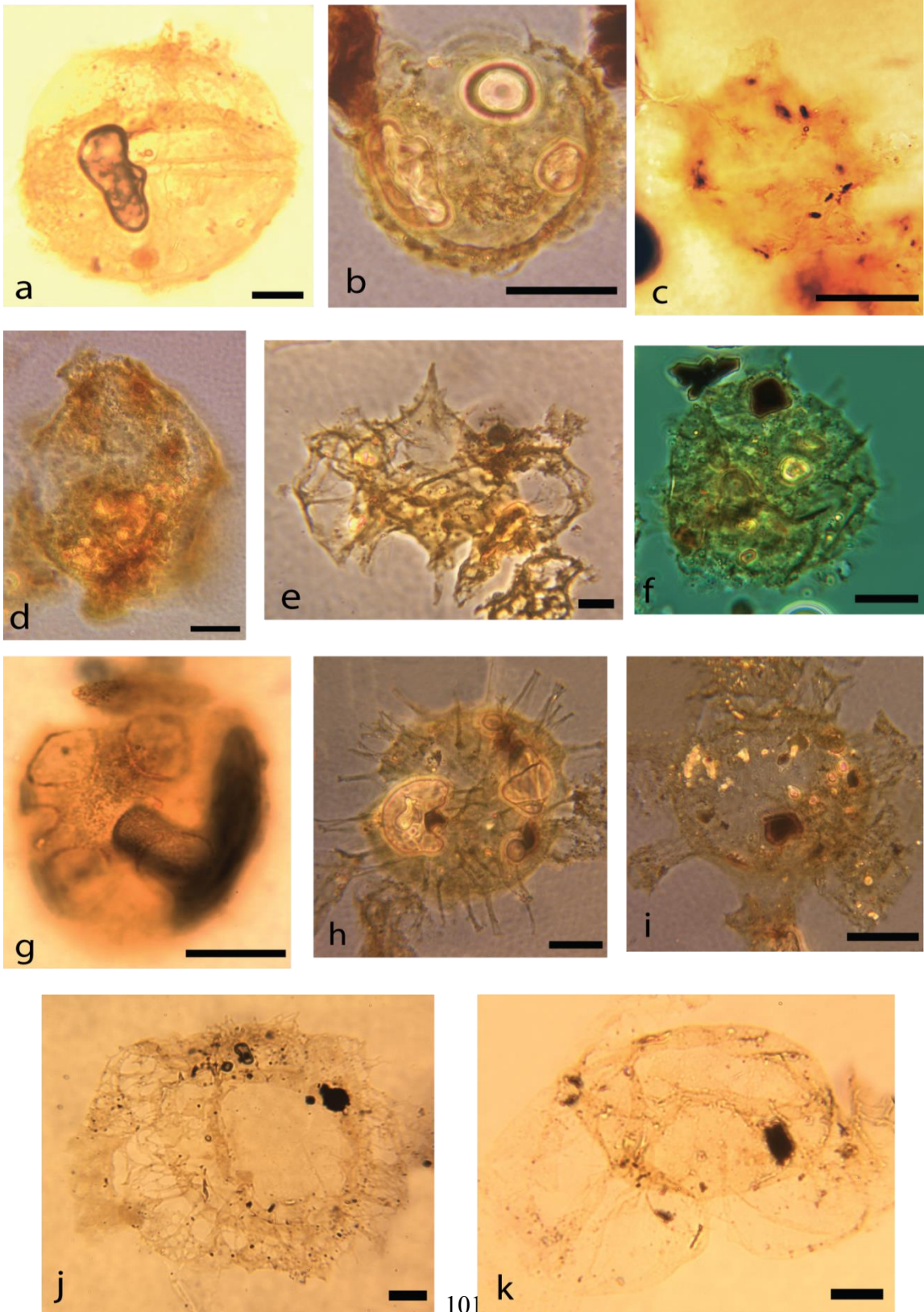


PLATE 5

Figure

- a. *Glaphyrocysta perforata* (hypocyst in focus)
- b. *Hafniasphaera* spp.
- c. *Glaphyrocysta reintexta*
- d. *Hystrichosphaeridium tubiferum* (archeopyle in focus)
- e. *Impagidinium* cf. *I. patulum*
- f. *Impagidinium cristatum* (hypocyst in focus)
- g. *Impagidinium cristatum* (epicyst in focus)
- h. *Impagidinium multiplex*
- i. *Impagidinium multiplex* (left side- dorsal view)
- j. *Impagidinium multiplex* (right side-dorsal view)
- k. *Ynezidinium pentahedrias* (archeopyle in focus)
- l. *Ynezidinium pentahedrias* (dorsal view)

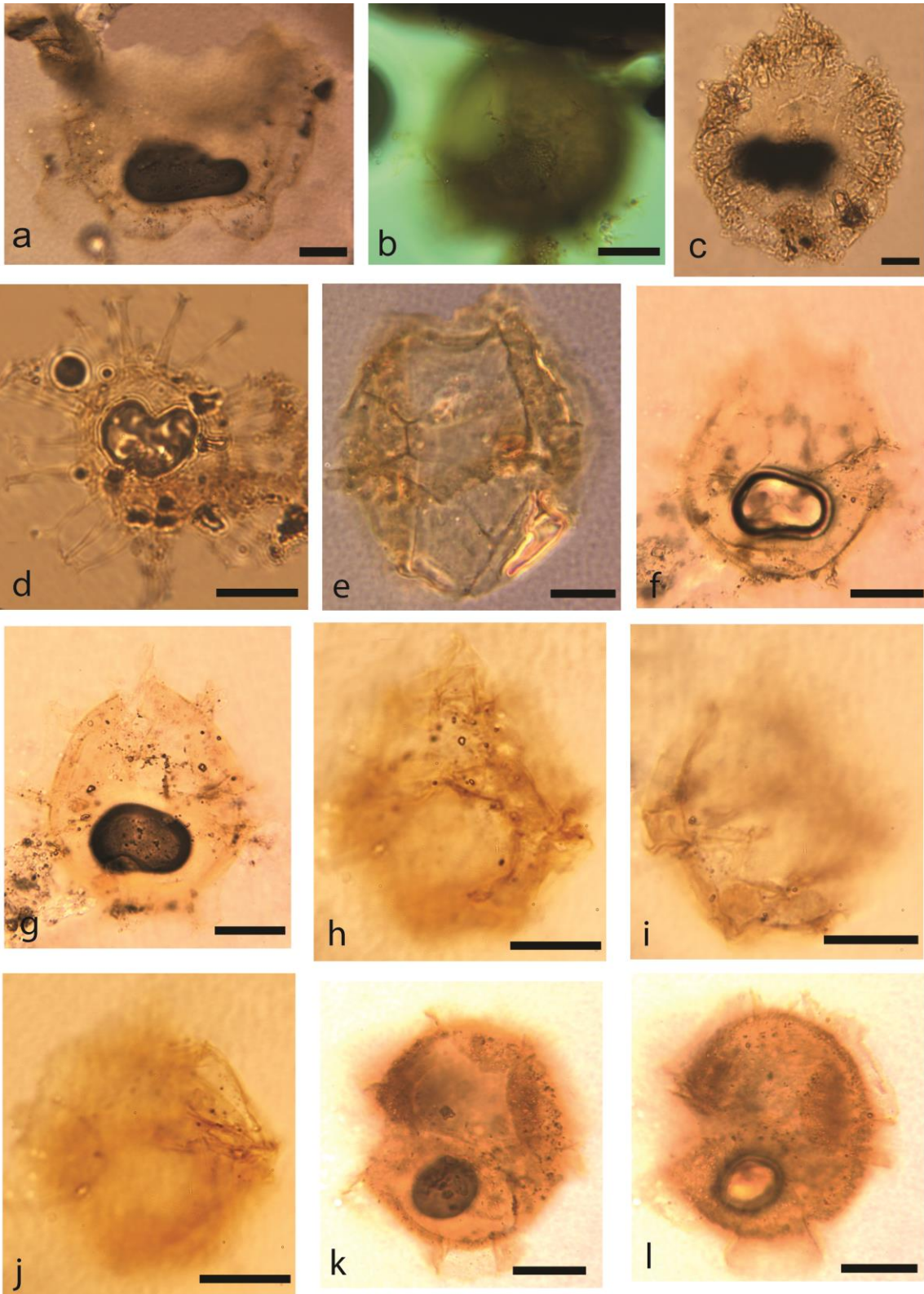


PLATE 6

Figure

- a. *Ynezidinium pentahedrias* (ventral view)
- b. *Oligosphaeridium complex*
- c. *Operculodinium centrocarpum*
- d. *Operculodinium radiculatum*
- e. *Palynodinium grallator* (note the Pericoel with small processes)
- f. *Spiniferites membranaceous* (ventral view)
- g. *Palynodinium* sp.1
- h. *Rottnestia* cf. *R.granulata*
- i. *Pterodinium cingulatum* (archeopyle in focus)
- j. *Pterodinium cingulatum* (ventral view)
- k. *Spiniferites ramosus*
- l. *Spiniferites ramosus* subsp. *reticulatus*

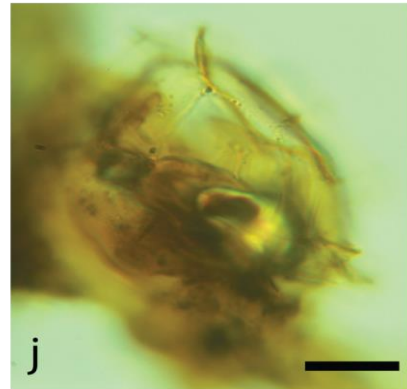
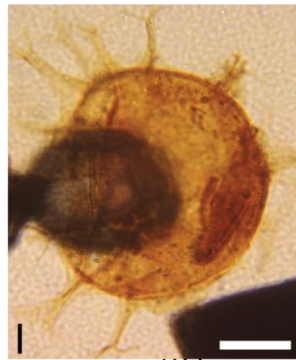
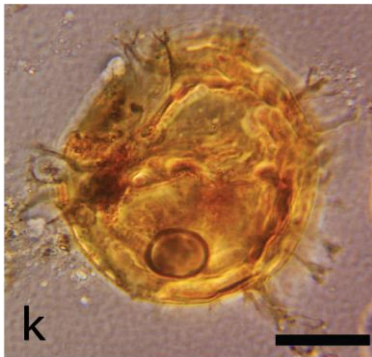
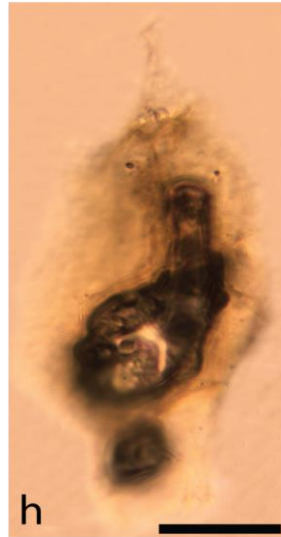
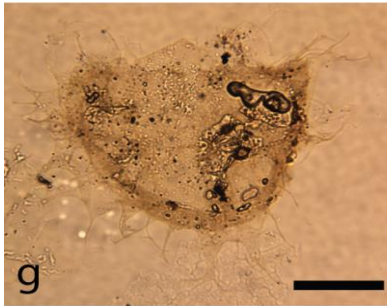
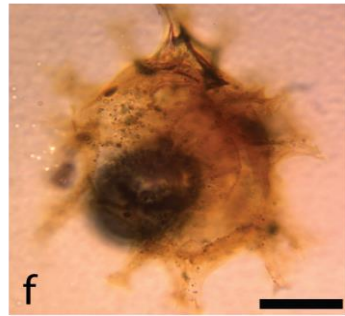
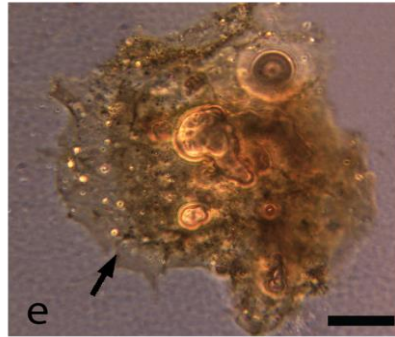
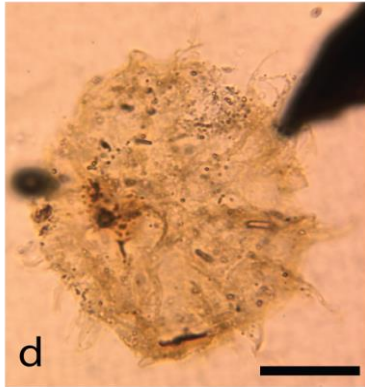
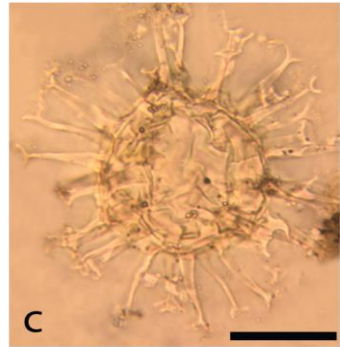
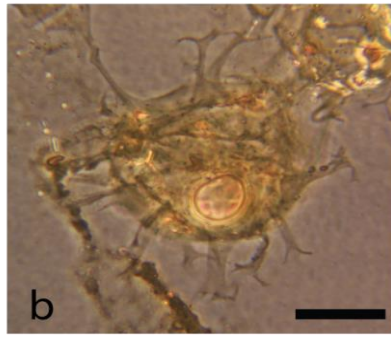
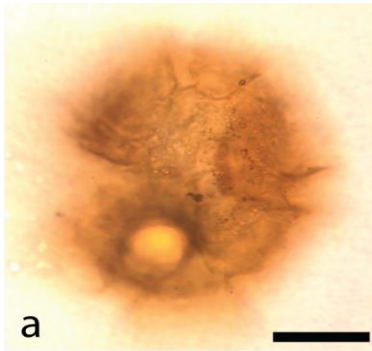


PLATE 7

Figure

- a. *Spongodinium delitiense* (hypocyst in focus)
- b. *Spongodinium delitiense* (epicyst in focus)
- c. *Tanyosphaeridium variecalamum*
- d. *Tectatodinium rugulatum* (archeopyle in focus)
- e. *Thalassipora pelagica*
- f. *Xenascus ceratoides*
- g. *Xenascus ceratoides*
- h. *Alterbidinium acutulum*
- i. *Alterbidinium acutulum* (archeopyle in focus)
- j. *Alterbidinium cf. A.circulum*
- k. *Alterbidinium cf.A.circulum*

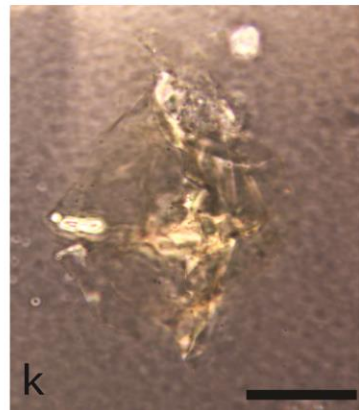
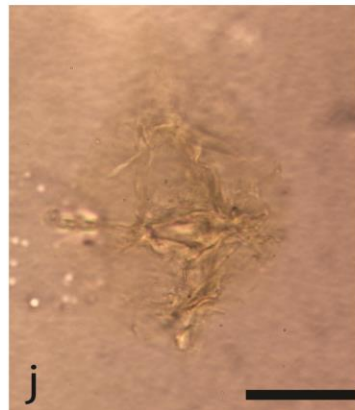
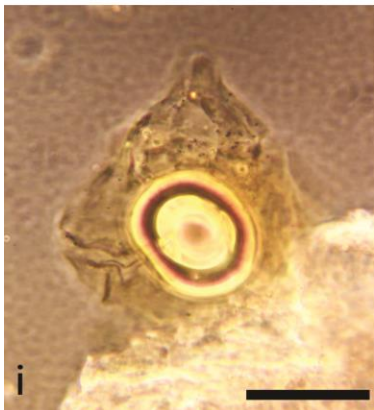
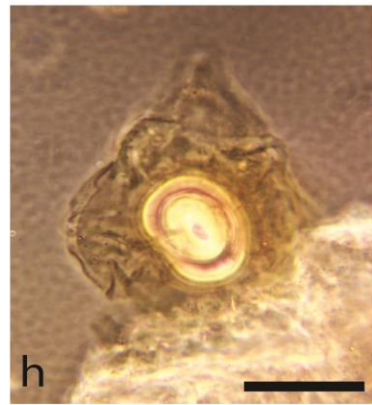
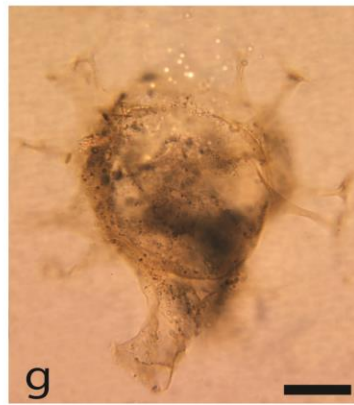
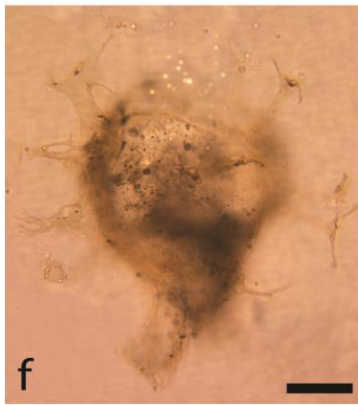
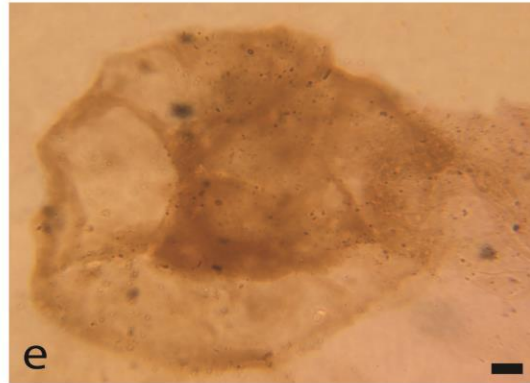
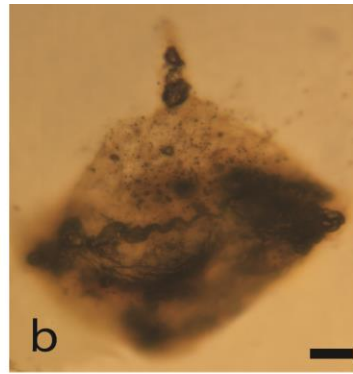
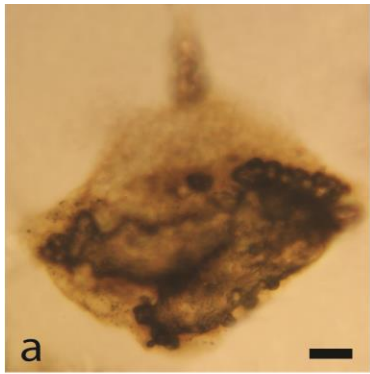


PLATE 8

Figure

- a. Andalusilla gabonensis* (note the antapical horn)
- b. Cerodinium diebelii* (ventral view)
- c. Cerodinium diebelii* (dorsal view)
- d. Cerodinium diebelii subsp. rigidum* (epicyst in focus)
- e. Cerodinium diebelii subsp. rigidum* (hypocyst in focus)
- f. Cerodinium leptodermum* (dorsal view)
- g. Cerodinium diebelii subsp. rigidum* (archeopyle in focus)
- h. Cerodinium pannuceum* (dorsal view)

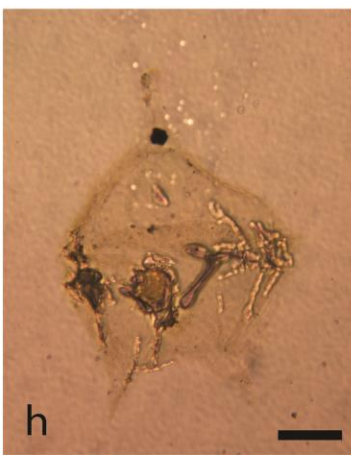
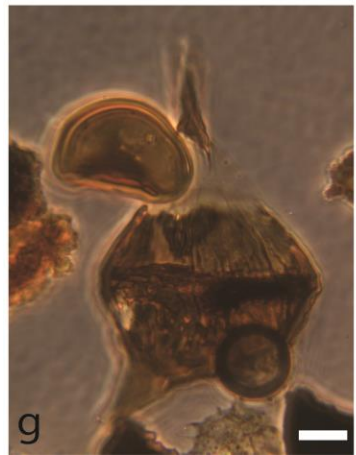
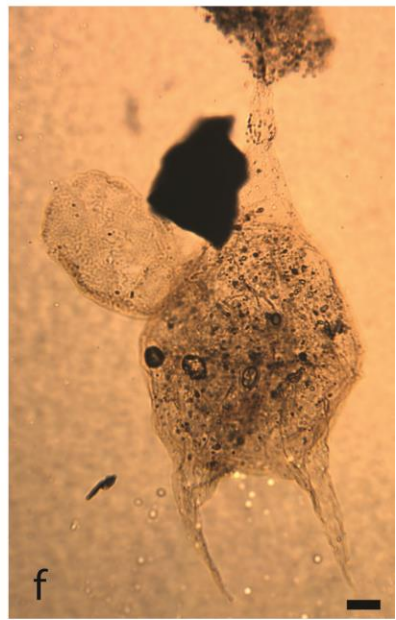
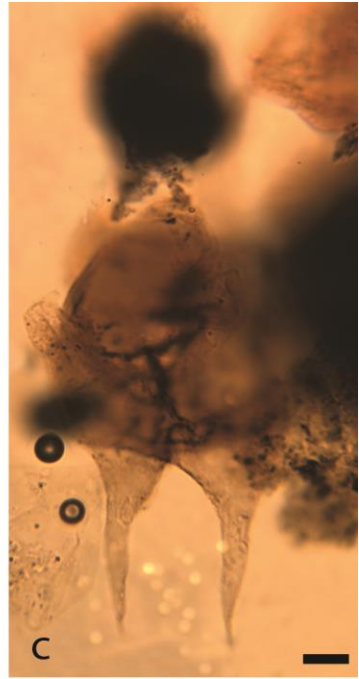
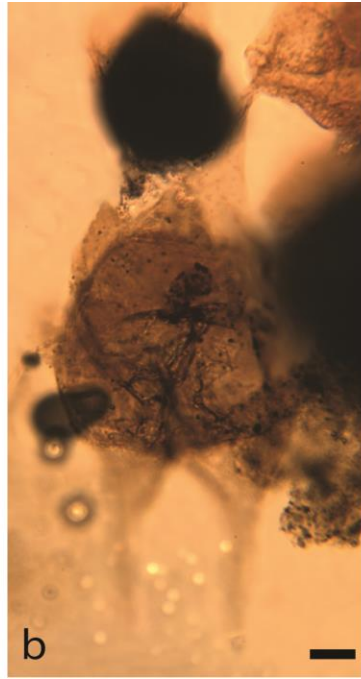
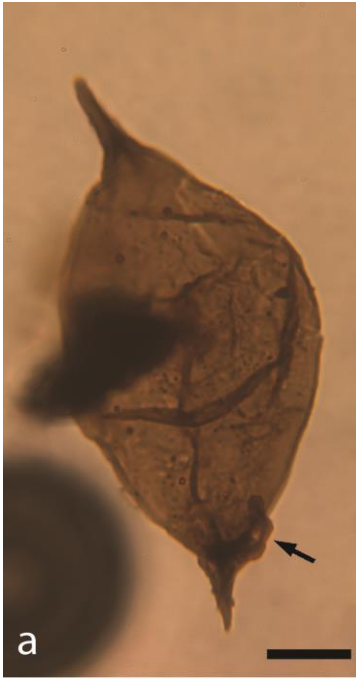


PLATE 9

Figure

- a. *Cerodinium speciosum*
- b. *Chatangiella ditissima* (epicyst in focus)
- c. *Chatangiella ditissima* (hypocyst in focus)
- d. *Chatangiella micrachanta* (hypocyst in focus-note the spines)
- e. *Chatangiella micrachanta* (epicyst in focus)
- f. *Chatangiella granulifera* (epicyst in focus)
- g. *Chatangiella granulifera* (hypocyst in focus)
- h. *Deflandrea galeata* (epicyst in focus)
- i. *Deflandrea galeata* (close up to granular periphragm)
- j. *Diconodinium psilatium*
- k. *Isabelidinium bakeri* (dorsal view)

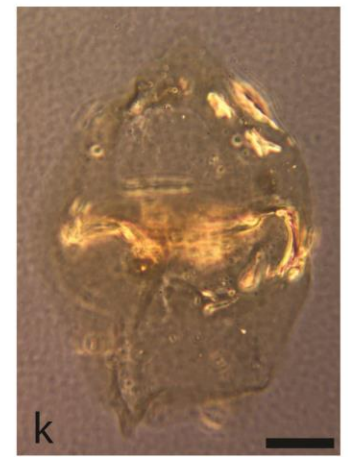
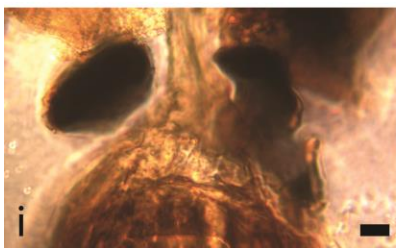
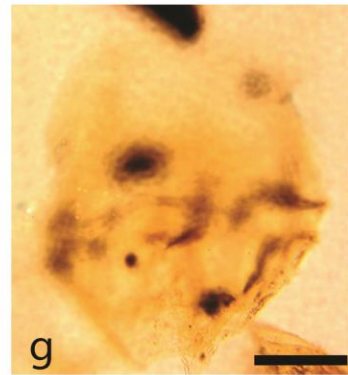
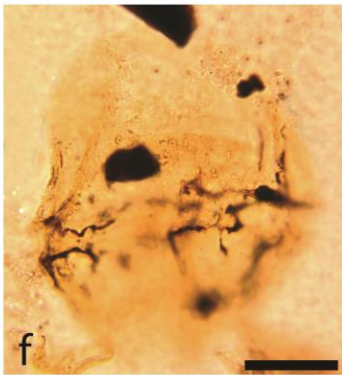
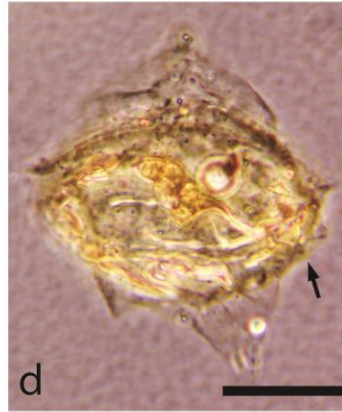
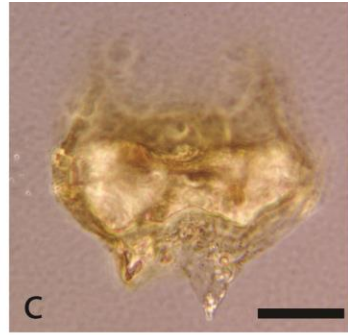
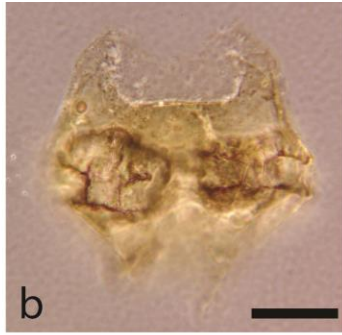
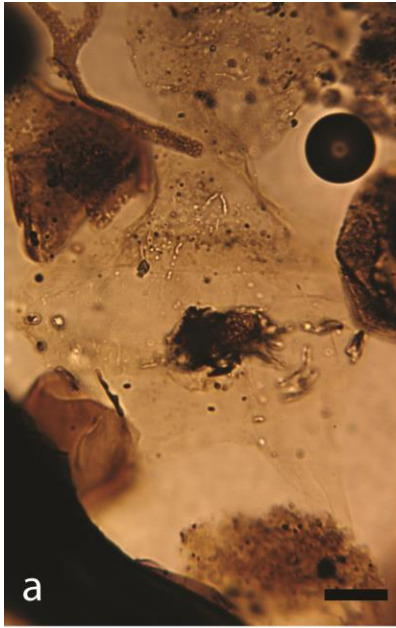


PLATE 10

Figure

- a. *Isabelidinium cooksoniae* (epicyst in focus)
- b. *Isabelidinium cooksoniae* (archeopyle in focus)
- c. *Isabelidinium cooksoniae* (paracingulum in focus)
- d. *Isabelidinium cooksoniae* (hypocyst in focus)
- e. *Isabelidinium sp.1* (ventral view-broken specimen)
- f. *Isabelidinium sp.1* (dorsal view-broken specimen)
- g. *Lejeunecysta sp.1* (ventral view)
- h. *Magallanesium cf. M.essoii* (ventral view)
- i. *Magallanesium densispinatum* (archeopyle in focus)
- j. *Magallanesium densispinatum* (dorsal view)
- k. *Manumiella druggii* (ventral view)
- l. *Manumiella druggii* (close up to granular periphragm)

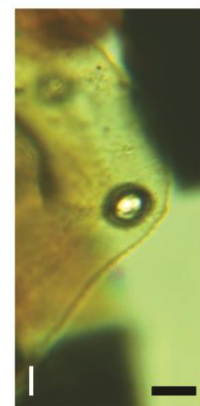
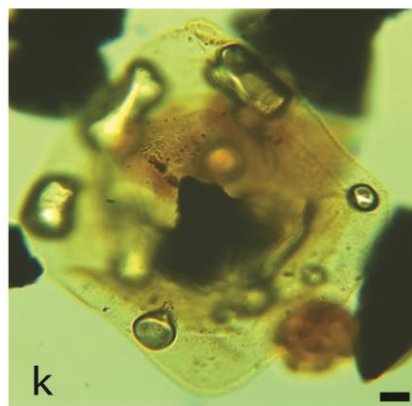
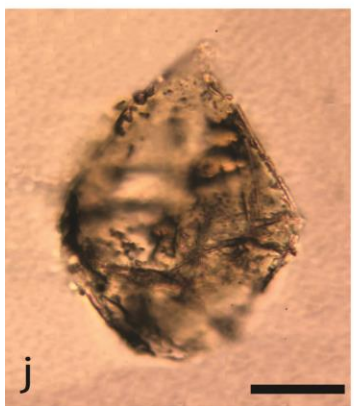
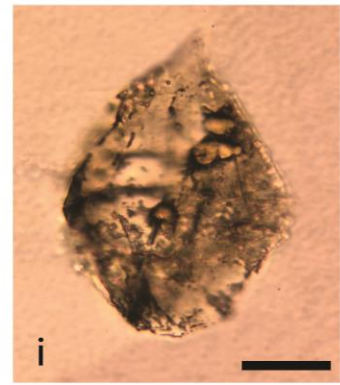
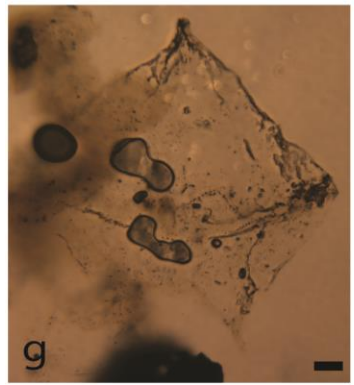
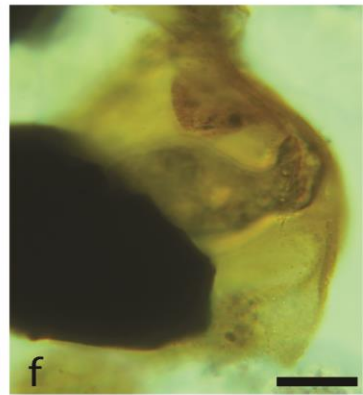
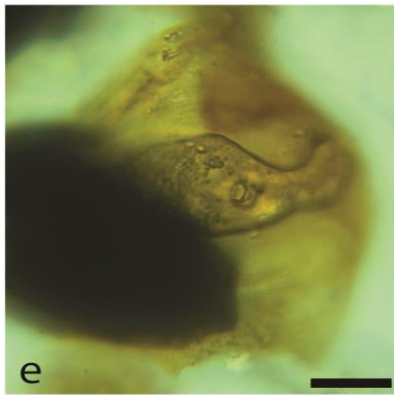
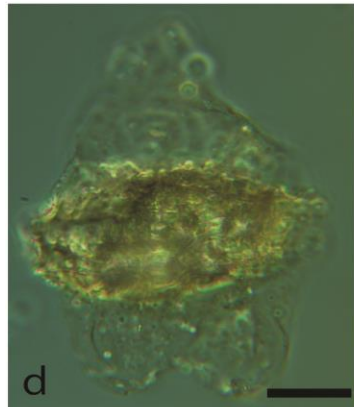
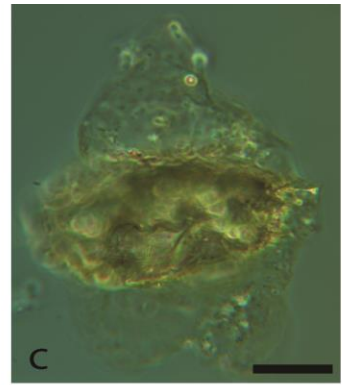
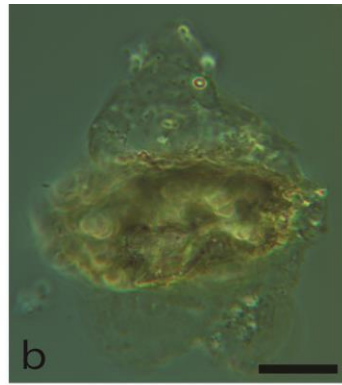
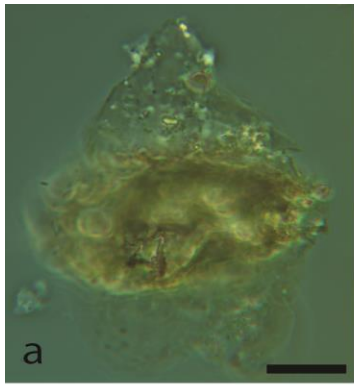


PLATE 11

Figure

- a. *Manumiella seymourensis* (right side of dorsal side in focus)
- b. *Manumiella seymourensis* (left side of dorsal side in focus)
- c. *Manumiella seymourensis* (note conical apex and antapex)
- d. *Paleocystodinium australinium*
- e. *Paleocystodinium golzowense* (hypocyst in focus)
- f. *Paleocystodinium golzowense* (epicyst in focus)
- g. *Phelodinium africanum* (dorsal view)
- h. *Phelodinium magnificum*
- i. *Pierceites pentagonus* (dorsal view)

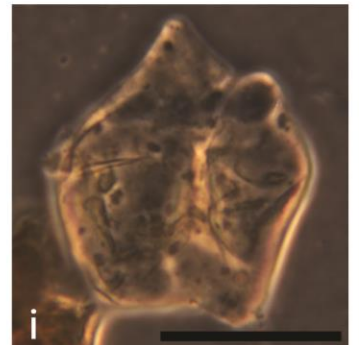
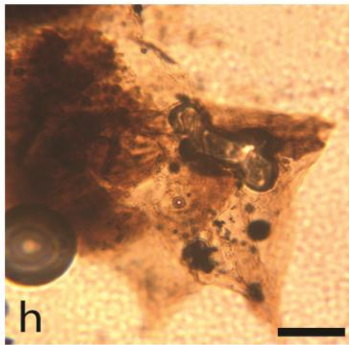
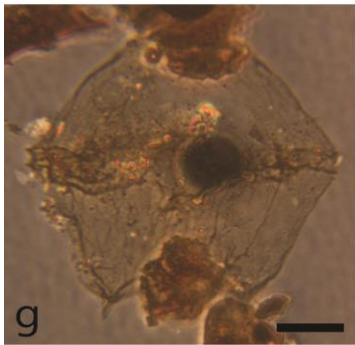
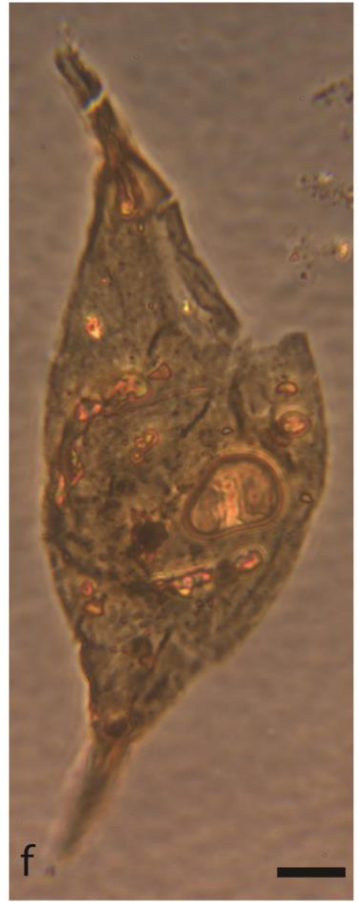
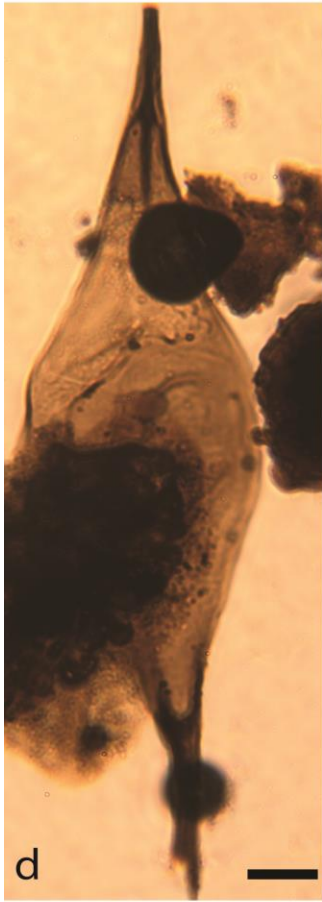
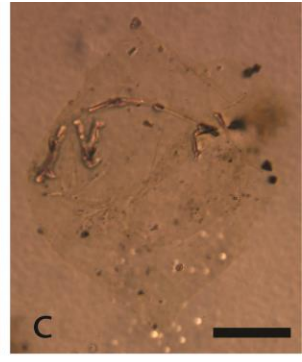
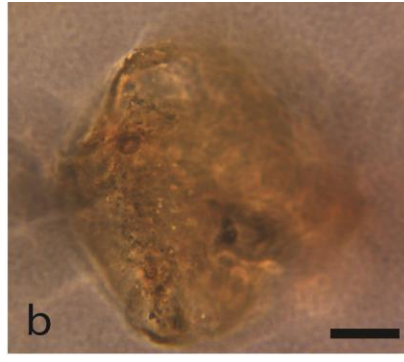
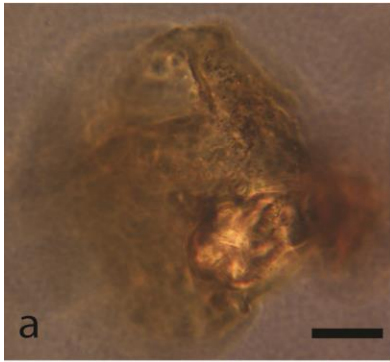


PLATE 12

Figure

- a. *Senegalinium bicavatum*
- b. *Senegalinium laevigatum*
- c. *Senegalinium microgranulatum*
- d. *Senegalinium obscurum*
- e. *Senegalinium pallidum*
- f. *Senegalinium simplex*
- g. *Senegalinium ornatum* (hypocyst in focus)
- h. *Senegalinium ornatum* (epicyst in focus)
- i. *Trithyrodinium evitii* (ventral view)
- j. *Trithyrodinium evitii* (dorsal view)

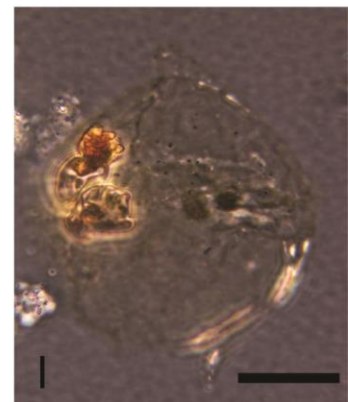
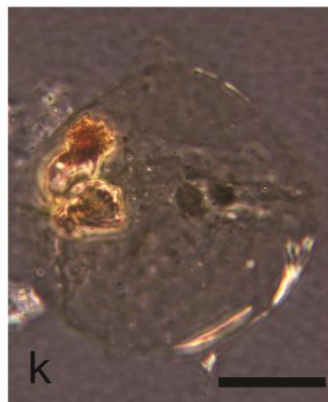
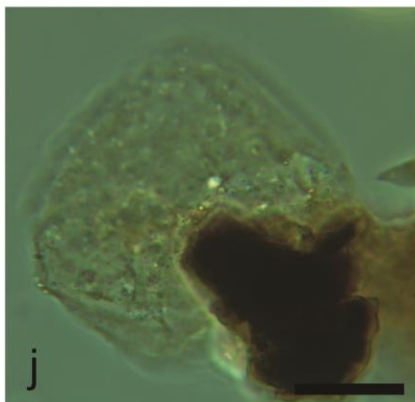
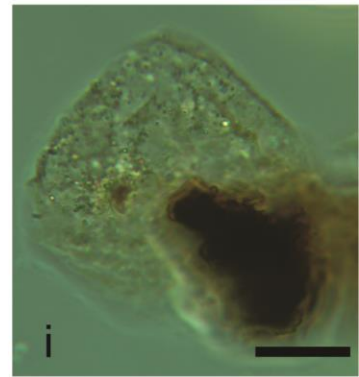
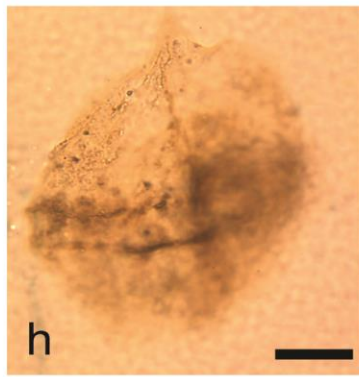
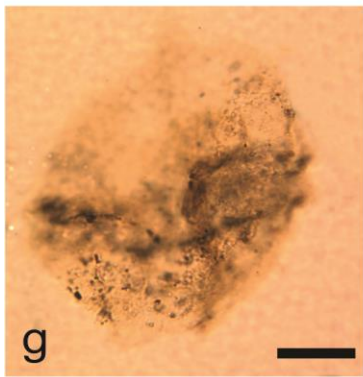
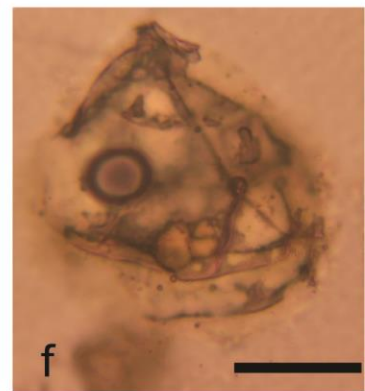
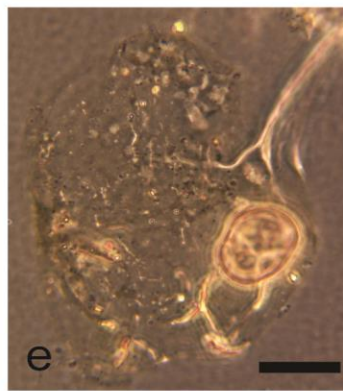
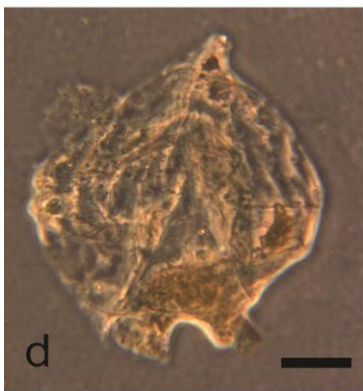
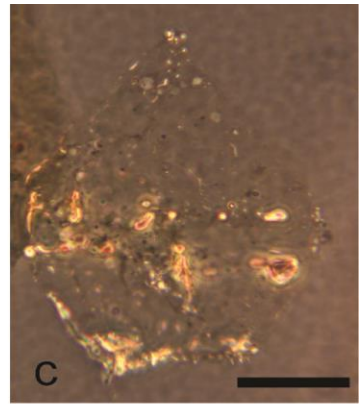
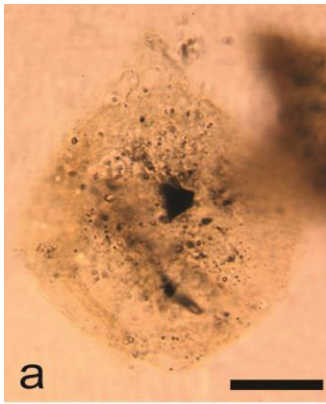


PLATE 13

Figure

- a.* Tricolporate spore
- b.* Wodehousia spinata
- c.* Triporate spore
- d.* Periporate pollen
- e.* Ephedripites sp.
- f.* Foraminifera linings
- g.* Acritarch sp.1
- h.* Acritarch sp.1

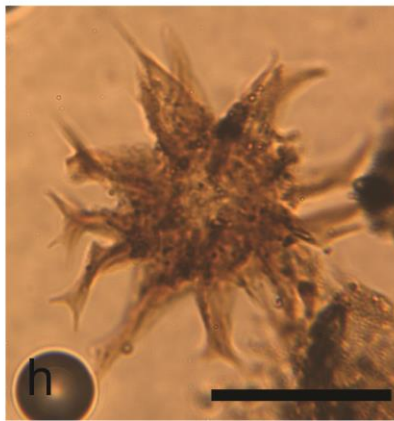
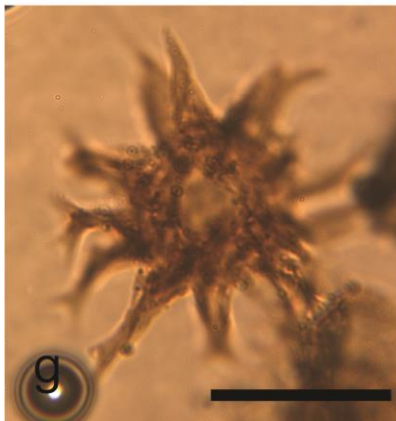
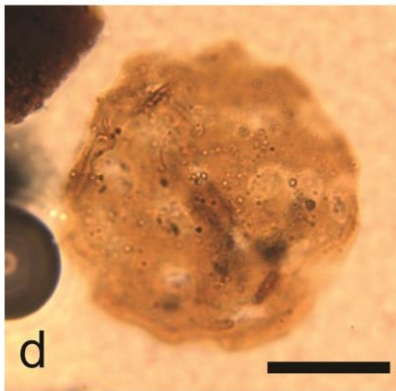


PLATE 14

Figure

- a. Achilleodinium sp.1*
- b. Achilleodinium sp.1*
- c. Apteodinium cf. A.granulatum*
- d. Apteodinium cf. A.granulatum*
- e. Cannosphaeropsis sp.1*
- f. Cannosphaeropsis sp.1*

